

METALS AND THEIR ALLOYS

A MODERN PRACTICAL WORK DEALING WITH
METALS FROM THEIR ORIGIN TO THEIR USE-
FUL APPLICATION—BOTH INDIVIDUALLY
AND AS PARTS OF ALLOYS—USED WHERE
STRENGTH, DUCTILITY, TOUGHNESS,
LIGHTNESS, COLOR, HARDNESS, CHEAP-
NESS, CONDUCTIVITY, OR BEARING
PROPERTIES ARE DEMANDED

BY

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Partly based on the Third Edition of "Metallic Alloys"

By William T. Brannt

Illustrated by One Hundred and Ten Engravings

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TO
MY VALUED FRIEND AND MENTOR
ADOLPHUS OTTO BACKERT
CLEVELAND, OHIO
THIS VOLUME IS GRATEFULLY DEDICATED

PREFACE

When it became necessary to publish a new edition of "Metallic Alloys," the work by the late Wm. T. Brannt which has been so long and favorably known, the fact was appreciated that the time had come for a more thorough revision than any to which previous editions had been subjected, if the ambition to produce a thoroughly modern and practical work was to be realized. But it was not then foreseen that the work of revision would shape itself into such a complete change that practically a new volume would result. Such, however, has been the case; and while this new volume is based on the noted work by Brannt, the superstructure is new, and a new title has been selected as more fittingly descriptive of its contents and scope.

The number of the illustrations in the old work has been doubled, and now includes sectional views of special and particularly interesting apparatus used in winning the metals from their combinations; half-tones and drawings of furnaces used to melt the metals and alloys; and microphotographs showing the structure of alloys and some of the impurities they may contain. The first part of the book is devoted to a short history of the individual elementary metals, giving the properties of the most important commercially. While it is hoped that the effort to collect and present accurate data has been successful, the proverb says "*Humanum est errare.*" The object of such presentation, however, is primarily to provide the busy, practical man with a source of information on such subjects, sufficiently accurate for his purpose and easy to refer to.

In the chapters dealing with the various alloys, the aim has been to treat them in a thoroughly practical and straightforward manner, eliminating vague references. The experience of others has been freely drawn on, and if credit

has been omitted, it was not intentional, and an apology is here tendered to all our friends.

The physical properties of the various alloys have been given when it was possible to obtain them, either from my private records or through others. As the physical properties of most non-ferrous alloys vary with the manner of making the test bars, in all cases where the figures given in the volume appear difficult of attainment, a study of the pages treating of test bars is suggested; and failing to discover what was hoped for, it will always be a pleasure for me to act as a court of last resort.

It has been the aim to make METALS AND THEIR ALLOYS a thoroughly practical book filled with the formulas most widely used, the presentation being made in as simple a manner as possible, and thus as easily available for the unskilled man as for the technically trained worker.

My personal experience covers a period of some forty years as a thoroughly practical foundryman, during which time I filled all positions in the industry; and my knowledge of what the foundryman wants is based on that experience, and also from my present connection with the *Foundry* and the *Brass World*.

We desire to acknowledge our indebtedness for permission to use certain matter to the American Institute of Mining and Metallurgical Engineers, the American Society for Testing Materials, the British Institute of Metals, the U. S. Bureau of Standards and U. S. Bureau of Mines, the International and Mond Nickel Companies; to all manufacturers who sent information and loaned illustrations of their products; to M. W. von Bernewitz of the Pittsburgh Experiment Station of the U. S. Bureau of Mines for his numerous practical suggestions and constructive criticism throughout the volume; and finally to all of our friends whom we may have laid under contribution in the endeavor to attain the high ideals with which we set out to revise Brann't's "Metallic Alloys."

CHARLES VICKERS.

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METALS AND THEIR ALLOYS

CHAPTER I

THE ELEMENTS

INTRODUCTION

ENORMOUS quantities of metals are extracted each year from their ores, much of which is used as the pure metal, but a great deal is employed as alloys—that is, solid solutions or homogenous mixtures of two or more metals. The reason for an alloy is because for many purposes the pure metal is unsuitable, but a mixture of two or more possesses the requisite properties. Every metal which we mine enters into the crust of the earth as a widely, almost generally, disseminated element. Iron and gold, to mention two very dissimilar metals, are found in all rocks; but only in spots are there local concentrations of the metals worth exploiting. Some idea of the amount of metal produced throughout the world in a normal (war periods and those immediately following are not normal) year—say, 1913—is obtained from a study of table 1, compiled from the “Mineral Industry” and statistics gathered by the U. S. Geological Survey.

Magnitude of the industry.—The metal-working industry (exclusive of mining and reduction) of the United States is of enormous proportions and importance, and the following figures showing this are culled from the census of manufactures for 1919, collected by the Bureau of the Census at Washington, D. C.:

In the iron and steel business, including products therefrom, were 20,120 establishments employing 1,585,712 per-

sons. The cost of the materials worked was \$4,815,885,004, and the value of the products manufactured was \$9,403,634,265. Included therein are 30 ferro-alloy plants employing 2344 persons, and producing \$38,583,984; and 1340 foundries with 104,816 persons, and products valued at \$421,049,258.

TABLE I.—*World's production of metals*

Metal	Unit	Quantity	Metal	Quantity
Aluminum...	Pounds	160,000,000	Molybdenum...	1,600,000
Antimony...		40,000,000	Nickel.....	35,000,000
Bismuth....		200,000	Platinum....	300,000
Cadmium....		200,000	Silver.....	221,000,000
Chromium...	Metric tons	170,000 ^a	Steel.....	76,100,000
Cobalt.....	Pounds	300,000	Thorium.....	2,600,000
Copper.....		2,000,000,000	Tin.....	135,000,000
For year 1918...	Long tons	296,000 ^b	Titanium (ore)...	30,000,000
Gold.....	Ounces	22,300,000	Tungsten....	35,000,000
Iron.....	Metric tons	79,100,000	Uranium.....	35,000,000
Lead.....		1,166,000	Zinc.....	35,000,000
Magnesium...	Pounds	80,000	Zirconium....	35,000,000
Manganese...	Metric tons	2,540,000 ^c		
Mercury....	Flasks of 75 lb.	100,000		

^a Oxide, say 115,000 tons metal. Not used as metal, only in alloys.

^b For year 1918, 750,000 tons, including cerium, chrome, manganese, molybdenum, silicon, titanium, tungsten, uranium, vanadium, and zirconium.

^c Ore, say 1,270,000 tons metal.

^d For year 1918 (approximate).

^e Thorium and cerium-bearing sands.

^f Oxide, say 4800 tons metal; not used as metal, only in alloys.

^g United States in 1920.

^h For year 1915.

ⁱ Minerals only.

The number of establishments—including foundries—working on all other metals and alloys totaled 10,667, employing 339,469 persons. The cost of raw materials was \$1,906,034,056, and the market value of the products was \$2,760,293,568. Among these were 1092 brass and bronze plants producing \$389,550,094; 118 babbitt metal and solder plants making \$59,016,983; 2054 were handling jewelry worth \$203,939,230; and 2200 were working on aluminum alloys.

It is difficult to procure any definite figures as to how much of the virgin metals is consumed in the manufacture of alloys, or what quantity of alloys is made therefrom, but the following approximate data concerning United States production may be of interest:

Fifty per cent of the yearly output of aluminum of this country is now converted into alloys, mostly into the 92-8 aluminum-copper alloy.

Of the copper production, approximately a third goes into brass and bronze, according to the Copper and Brass Research Association. One company alone—the American Brass Co., a subsidiary of the Anaconda Copper Mining Co.—consumes 300,000,000 lb. of copper per annum.

Practically all antimony is used in alloys.

It was estimated in 1919 that 400,000 tons of ferro-alloys, valued at \$47,000,000, were manufactured and shipped within the country. Ferro-manganese and spiegeleisen accounted for 75% of this total; ferro-silicon and ferro-phosphorus for 24%; and ferro-cerium, ferro-chromium, ferro-molybdenum, ferro-titanium, ferro-tungsten, ferro-uranium, ferro-vanadium, and ferro-zirconium the remainder.

Gold and silver are not used to a large extent in their pure form, but are alloyed with copper or with one another. According to the Director of the U. S. Mint, the world's coinage in 1920 absorbed 2,030,000 oz. of fine (pure) gold and 216,340,000 oz. of fine silver. And new gold and silver consumed in manufactures and the arts during the same year were 2,610,000 oz. and 19,280,000 oz. respectively; so it will be seen that the alloying of the precious metals is a big industry.

Bearing metals, solder, and type metal are the outlet for the lead used in alloys, but this is probably only 10% of the total output of virgin metal. Half of the lead is consumed in paint and storage-battery oxides, and a good deal in foil, shot, sheet, and cable conduits.

The principal use of nickel is in nickel steel which absorbs about 65% of the metal, followed by 10% in nickel silver, and about another 5% in miscellaneous alloys, according to the Mond Nickel Co.

Of the tin, between 40 and 50% goes into alloys.

Of the zinc, about 45% is used in manufacturing alloys—that is, with copper mainly—according to the American Zinc Institute.

PROPERTIES OF METALS

Before entering upon a description of the manufacture of alloys it will be in order to give a general review of the physical and chemical properties of the metals.

Most readers, no doubt, possess this information; but memory might fail some of them, and some essential details, though perhaps elementary, may escape others, therefore such matter is included herein.

The elements are generally divided into two great groups, namely, metals and non-metals. This classification dates from a time when certain physical properties were ascribed to the metals, which were thought to be peculiar to them and also considered suitable for their distinction from the non-metals. Such characteristic and peculiar properties of the metals were, for example, their luster, conductivity for heat and electricity, high specific gravity (above 6), and so forth.

It is now known that none of these physical characteristics belong exclusively to the metals. Iodine, tellurium, and graphite possess metallic luster. Tellurium conducts heat; and graphite, as well as selenium (in a less degree) conducts electricity. On the other hand, there are metals—potassium and sodium, for instance—of which the specific gravity is not only less than 6, but which are even lighter than water.

The exact meaning of the words “metals” and “non-metals” cannot be sharply defined, as it is impossible to say what properties are exclusively peculiar to the former and what to the latter, just as it is impossible to classify exactly any series of natural substances. However, certain distinctive characteristics of the metals to be considered in connection with the manufacture of alloys can be given without difficulty.

PHYSICAL RELATIONS OF THE METALS

By the ordinary use of the term metal we understand it to mean a body, which, besides having a high specific gravity, characteristic color, and especially a characteristic luster,

shows other definite properties. It is, for instance, frequently supposed that all metals possess a high degree of ductility, that they are opaque, fuse only at a high temperature, and on exposure to the air undergo a slow alteration; or, as is the case with the so-called noble metals, retain their color under all conditions.

The properties mentioned undoubtedly belong to the metals ordinarily understood by that term, and chiefly used in the industries. In considering, however, the bodies termed metals from the standpoint of the chemist, we find that many of them, which must unquestionably be included in that group, show properties differing very much from those enumerated above. If we first turn to the common metals, we find them distinguished by a characteristic luster, termed "metallic luster," this property being even possessed in a very high degree by such metals as appear entirely lusterless in consequence of their chemical properties—that is, in contact with the air. If a piece of lead be cut with a knife, the fresh surface shows a beautiful luster, but this will very speedily tarnish on exposure to the air by the lead undergoing rapid alteration.

Besides high specific gravity and metallic luster, other general properties are ordinarily ascribed to metals, prominent among which is malleability. It is, however, well known to every one handling metals that they manifest great variations in capacity for extension under the hammer or between rolls. Some of them, like gold and silver, may be obtained in exceedingly thin leaves; while others, like antimony and bismuth, appear to be perfectly non-malleable. Similar differences are noticeable in the ductility of the metals—some of them can be drawn out into very fine wire, while others are altogether lacking in ductility.

Even the property of opacity belongs only conditionally to the metals, as gold and silver are translucent in thin plates, the former transmitting green and the latter blue rays, though none of the other metals have been obtained in sufficiently thin leaves to allow of the transmission of light.

It will thus be seen that the properties of metals vary

very much from those ordinarily ascribed to them, and the same must be said in regard to their fusibility. While some fuse at a low temperature—even below that of boiling water (212° F.)—others melt only at a red heat, a strong red, or a white heat. The temperatures corresponding to different colors are explained in the following comparison by Pouillet:

<i>Color</i>	$^{\circ}$ F.	<i>Color</i>	$^{\circ}$ F.
Incipient red heat.....	977	Deep orange.....	2012
Dull red.....	1292	Clear orange.....	2192
Incipient cherry-red.....	1472	White.....	2372
Cherry-red.....	1652	Bright white.....	2552
Clear cherry-red.....	1832	Dazzling white.....	2732

Some of the metals soften before actual fusion takes place, so that they can be hammered or welded into compact masses.

There are, however, some points in which all the metals agree, as follows:

1. They are distinguished by great weight—lead, iron, gold, and platinum being representatives of those prominent in this respect.

2. They are, as a rule, very ductile bodies—copper, silver, gold, and others being representatives of this group. Others like antimony, bismuth, and zinc, show, however, a high degree of brittleness.

3. With the exception of mercury and gallium, they are all solids at the ordinary temperature, and become liquid only at higher temperatures.

4. They are, without exception, excellent conductors of heat and electricity—that is, they rapidly absorb them, but just as rapidly yield those forces up again.

5. Finally, it remains to be remarked that the metals show considerable differences in regard to specific gravity, ductility, conductivity, and so forth, which will be referred to in discussing the special properties of the metals available for alloys.

The Elements

CHEMICAL RELATIONS OF THE METALS

Chemically, the metals are distinguished by their ability to form combinations with the non-metallic elements, the combinations with the oxygen of the air being especially energetic. The affinity of the different metals for oxygen, however, varies greatly, the majority of the metals commonly used combining with it at an ordinary temperature. This phenomenon can be readily observed on the piece of lead previously mentioned. The fresh surfaces lose their luster by the lead combining with the oxygen of the air, which gives rise to a coating of oxide. Copper, having less affinity for oxygen, remains bright for some time, and then acquires a brownish-red color, which is also due to the formation of a film of oxide. Many other metals remain bright at normal temperatures, and only lose their characteristic luster by oxidation taking place at a higher temperature—this last phenomenon being, for instance, observed with tin and antimonial metals which become oxidized on heating. In other words, all metals losing their metallic luster at normal temperatures, or by heating, are termed “base metals,” while the term “noble metals” is applied to those which have so little affinity for oxygen that they cannot be induced directly to unite with it even at high temperatures. The number of noble metals is very small in comparison with that of the base metals, and of those more frequently used—mercury, silver, gold, and those of the platinum group being the only ones in the group.

From what has been said, it will be seen that the metals may be divided according to their behavior towards oxygen, such a division being in fact well supported, as will be shown later.

In a chemical sense, the metals can be further divided with reference to certain physical properties into heavy and light metals. There is a series of metals whose specific gravity is so low that they float upon water, that of some of them being not greater than ordinarily exhibited by glass. Chemists

term such metals "light metals," in contradistinction with those of great weight.

The properties of the light and heavy metals allow, however, of an easy separation as regards their chemical relations; and, by taking these relations into consideration, the result will be a suitable division of the metals into determined groups, which, together with their special properties, will be mentioned.

The metals belonging to the group of light metals have a very low specific gravity, not exceeding 4, the weight of a volume of water being always taken as the unit 1. These metals find but limited utilization alone, most of them having such a strong affinity for oxygen as to be speedily converted into oxide on coming into contact with the air. Only two of them—magnesium and aluminum—are exceptions in this respect. According to their occurrence, these metals are divided into three groups, namely, the alkali metals, the alkaline earth metals, and the earth metals.

The first group includes lithium, sodium, potassium, rubidium, and caesium. Of these, potassium and sodium are a little lighter than water, and lithium a little more than half as heavy. The metals of the alkalies are characterized by their strong chemical affinities for negative elements, and are, therefore, well adapted for withdrawing oxygen, sulphur, and chlorine from combination with other elements. They are known as powerful reducing agents.

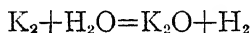
The metals of the alkaline earths have somewhat similar properties to the metals of the alkalies. Included in this group is calcium, occurring in gypsum, limestone and many other minerals; barium, contained in barite or heavy spar, and strontium, the principal naturally occurring compounds of which are the sulphate, celestite, and the carbonate, strontianite. Like the alkali metals, the metals of the alkaline earths do not find direct application, their affinity for oxygen rendering such use impossible.

The earth metals comprise aluminum, scandium, yttrium, samarium, and helium. The last mentioned is a non-flam-

The Elements

mable gas. Only one of the elements of the earth metals has any claim to our attention in this work, and that is aluminum, probably the most important of the non-ferrous metals.

All light metals have the property of readily decomposing water, the metals of the alkalis and metals of the alkaline earths effecting this at an ordinary temperature. When a piece of potassium is thrown upon water, a vigorous development of hydrogen immediately takes place. The metal "melts" as a result of the heat liberated by the chemical reaction, and the hydrogen developed ignites. The metal combines immediately with the oxygen to form potassium oxide, which dissolves in water, according to the equation



After the combustion of the potassium, a colorless globule, consisting of the melted potassium oxide, floats upon the surface of the water. With a peculiar fizzing noise this globule suddenly bursts into pieces, which speedily dissolve in the water to potassium hydroxide. Sodium acts in a similar manner.

The earth metals act less energetically on coming in contact with water, though they decompose it at a boiling heat; magnesium, for instance, when strongly heated in contact with air, burns freely, light and heat being developed.

The heavy metals—that is, those which are commonly used—can, according to their chemical behavior, be brought into four well-defined groups, the group into which each metal is placed depending upon its behavior in contact with steam or with water in the presence of an acid, as follows:

1. Metals that decompose water at ordinary temperatures in the presence of an acid, and possess the further property of decomposing water at a higher temperature (red heat). To this group belong iron, zinc, nickel, cobalt, chromium, cadmium, tin, and a few rarer metals.

2. Metals that decompose water at the temperature of a red heat, but lack the property of decomposing water in the

presence of an acid. Of the more important metals, only antimony and tungsten belong to this group.

3. Metals that are incapable of sensibly decomposing water either at a red heat or in the presence of an acid, and are entirely indifferent towards it at an ordinary temperature. The metals belonging to this group, of which bismuth, lead, copper, and mercury are representatives, possess, however, the property of oxidizing when heated red hot in contact with air.

4. The precious metals are those that do not combine with oxygen when strongly heated in contact with air, and at a red heat remain entirely indifferent towards water. Silver, gold, and platinum are the most important metals in this group.

In addition to the metals enumerated in the preceding groups there are a number of others, which, according to their behavior, belong to one or the other. But, as previously mentioned, these metals are of no technical importance, being, on account of their rarity, too expensive to be used for industrial purposes. A more extensive use may, however, be found for them in the future, as has been the case with nickel, with which nothing could be done for a long time, but which is now used in large quantities for electroplating, and in the preparation of very important alloys.

While some metals possess the property of considerably hardening other softer and more ductile metals, some non-metallic bodies exert a still greater influence upon the properties of a metal; so it will, therefore, be necessary briefly to consider these bodies:

Carbon, sulphur, phosphorus, and arsenic are the most prominent of the non-metallic bodies which are capable of changing to a considerable degree the properties of a metal, and these being much used for that purpose in the industries, we will have to consider their combinations with the metals, though they do not belong to the actual alloys. The exceedingly great influence exerted by these bodies upon the properties of metals, even if admixed only in very small quantities, can be illustrated by the behavior of iron.

Pure iron is tough, ductile, and malleable. It can be welded, but it cannot be tempered. Though known as pure iron, it is never really pure, as it will contain from 0.095 to 0.017% of impurities. It is noted chiefly for its resistance to corrosion. Commercially pure iron, or wrought iron which is much less than 99.905% iron, is extensively used for purposes where toughness and reliability is demanded. For instance, for making the links of chains and crane-hooks; also, at one time marine shafting was invariably made of such material, with the result that very few wrought-iron shafts were fractured in service. The strength of wrought iron is low when compared with steel, being about 50,000 lb. per square inch. To increase its strength, a very small quantity of the foreign bodies we are considering is added to the iron. It then is known as steel, and its strength may be more than doubled.

Steel is merely alloyed iron. The total amount of the alloyed substances may be incredibly small, and yet produce the most profound changes in the character of the iron. Thus, piano wire will contain about 1.20% of such elements as carbon, manganese, silicon, phosphorus, and sulphur, but this small amount of impurity increases the strength of the original iron wire from 85,000 to 300,000 lb. per square inch, and over.

As is well known, the properties of steel are quite different from those of iron. It is harder, more elastic, and more tenacious, and fuses somewhat more readily. By still further increasing the carbon in the iron to about 3% we have what is known as cast iron. It is more fusible than steel, but brittle, and cannot be worked under the hammer as it cracks. According to the content of carbon it shows a gray to nearly white color and a crystalline structure.

A very small quantity of sulphur or phosphorus exerts a still greater effect upon the properties of iron than does one of carbon. Iron, containing but a few thousandths of sulphur, can only be worked in the "heat"; if hammered in the "cold" it cracks, it having become what is termed "cold-short"—that

is, brittle when cold. With a still smaller content of phosphorus, the iron cannot be worked with the hammer, even at red heat, and at a white heat cracks under the hammer; it having become "red-short" or "hot-short." The admixture of carbon, sulphur, and phosphorus with the metals is frequently an unintentional one, it being due to their being natural constituents of the ores reduced.

Before proceeding with the description of the properties of the alloys and the manner of their manufacture, it will be in order to give a short sketch of the special properties of the metals. As previously mentioned, some metals can be readily combined according to certain proportions. In such case we have not alloys in the actual sense of the word—that is, solid solutions of metals—but rather chemical combinations.

By a chemical combination is understood the union of two or more simple elements in unalterable proportions or multiples thereof. Each element possesses the property of combining with the other according to a proportion of weight admitting of no variation whatever, and the quantity of weight which enters into the combination, and is capable of so completely invalidating the properties of the other bodies that, so to speak, a new body is formed and is termed the atomic or indivisible weight. The names of the most important elements are given in table 2, together with their symbols and atomic weights, which express the proportions in which they combine together, or simple multiples of those proportions. The symbols are formed of the first letters of their names derived either from the Latin or Greek. Hydrogen is, for instance, represented by the letter H, from the word *hydrogenium*; oxygen by O, from *oxygenium*; silver by Ag, from *argentum*. If Latin or Greek names of several elements have the same first letters, the first letter serves only for the designation of one of these elements, while for the other elements the first letter is supplemented by an additional characteristic letter. Thus, for instance, boron is represented by the letter B; barium by Ba; bismuth by Bi; and bromine by Br.

TABLE 2.—*International atomic weights (1921-22 *)*

Element	Symbol	Atomic weight	Element	Symbol	Atomic weight
Aluminum.....	Al	27.0	Molybdenum....	Mo	86.0
Antimony.....	Sb	120.2	Neodymium.....	Nd	144.3
Argon.....	A	39.9	Neon.....	Ne	20.2
Arsenic.....	As	74.96	Nickel.....	Ni	58.68
Barium.....	Ba	137.37	Niton.....	Nt	222.4
Bismuth.....	Bi	209.0	Nitrogen.....	N	14.008
Boron.....	B	10.9	Osmium.....	Os	190.9
Bromine.....	Br	79.92	Oxygen.....	O	16.0
Cadmium.....	Cd	112.40	Palladium.....	Pd	106.7
Calcium.....	Ca	40.07	Phosphorus.....	P	31.04
Carbon.....	C	12.005	Platinum.....	Pt	195.2
Cerium.....	Ce	140.25	Potassium.....	K	39.10
Cesium.....	Cs	132.81	Praseodymium...	Pr	140.9
Chlorine.....	Cl	35.46	Radium.....	Ra	226.0
Chromium.....	Cr	52.0	Rhodium.....	Rh	102.9
Cobalt.....	Co	58.97	Rubidium.....	Rb	85.45
Columbium.....	Cb	93.1	Ruthenium.....	Ru	101.7
Copper.....	Cu	63.57	Samarium.....	Sa	150.4
Dysprosium....	Dy	162.5	Scandium.....	Sc	45.1
Erbium.....	Er	167.7	Selenium.....	Se	79.2
Europium.....	Eu	152.0	Silicon.....	Si	28.1
Fluorine.....	F	19.0	Silver.....	Ag	107.88
Gadolinium....	Gd	157.3	Sodium.....	Na	23.0
Gallium.....	Ga	70.1	Strontium.....	Sr	87.63
Germanium.....	Ge	72.5	Sulphur.....	S	32.06
Glucinium.....	Gl	9.1	Tantalum.....	Ta	181.5
Gold.....	Au	197.2	Tellurium.....	Te	127.5
Helium.....	He	4.0	Terbium.....	Tb	159.2
Holmium.....	Ho	163.5	Thallium.....	Tl	204.0
Hydrogen.....	H	1.008	Thorium.....	Th	232.15
Indium.....	In	114.8	Thulium.....	Tm	169.9
Iodine.....	I	126.92	Tin.....	Sn	118.7
Iridium.....	Ir	193.1	Titanium.....	Ti	48.1
Iron.....	Fe	55.84	Tungsten.....	W	184.0
Krypton.....	Kr	82.92	Uranium.....	U	238.2
Lanthanum....	La	139.0	Vanadium.....	V	51.0
Lead.....	Pb	207.20	Xenon.....	Xe	130.2
Lithium.....	Li	6.94	Ytterbium.....	Yb	173.5
Lutecium.....	Lu	175.0	Yttrium.....	Yt	89.33
Magnesium....	Mg	24.32	Zinc.....	Zn	65.37
Manganese.....	Mn	54.93	Zirconium.....	Zr	90.6
Mercury.....	Hg	200.6			

* By F. W. Clarke, T. E. Thorpe, and G. Urbain, in the *Journal of the American Chemical Society*, vol. 43, August, 1921, p. 1752.

The symbols not only represent the elementary bodies, but also their fixed quantities by weight—namely, their atomic weights—so that, for instance, the symbol Ni means 58.68 parts by weight of nickel.

Compounds produced by the union of the elements are

represented by placing their corresponding symbols together and designating them "chemical formulas." For instance, common salt consists of one atom of sodium (Na) and one atom of chlorine (Cl), hence its formula has to be written NaCl. The latter shows that one molecule of common salt consists of 23 parts by weight of sodium and 35.46 parts by weight of chlorine, which together form 58.46 parts by weight of common salt. If several atoms of an element are present in a compound, this is denoted by numbers which are attached to the symbol of the atom. Water consists of two atoms of hydrogen (H) and one atom of oxygen (O), and hence its formula is H_2O , which shows that two parts by weight of hydrogen, together with 16 parts by weight of oxygen form 18 parts by weight of water.

CLASSIFICATION OF METALS

As will be noted; the table of atomic weights is arranged alphabetically, but this is not the order in which the elements are classified in works on chemistry when dealing with their properties, because it takes no note of the fact that certain elements greatly resemble one another; and that by arranging them in families according to this resemblance the study of chemistry is greatly simplified. But, as some members of a family, while clearly related, are markedly different in their properties to the other members of the same family, it has been found convenient to subdivide the families into groups designated alphabetically. Thus, in the case of family 1, the elements lithium, sodium, potassium, rubidium, and caesium, known as the alkali metals, greatly resemble one another, but bear little external resemblance to copper, silver, and gold. Nevertheless, some of the properties of the latter metals are such they appear to fall naturally into the same family as the alkali metals, but owing to their strongly marked differences they are placed in a different group of the same family. Thus the alkali metals are classified in family 1, group A, and copper, silver and gold in family 1, group B. The following

division (table 3) into families and groups was proposed by Lothair Meyer in about the year 1870, in order to make clear the connection between the properties and the atomic weights of the elements:

TABLE 3.—*Families and groups of elements*

<i>Family 1, Group A</i>			
Lithium.....	6.94	Rubidium.....	85.45
Sodium.....	23.0	Caesium.....	132.81
Potassium.....	39.10		
<i>Family 1, Group B</i>			
Copper.....	63.57	Gold.....	197.20
Silver.....	107.88		
<i>Family 2, Group A</i>			
Glucinium.....	9.10	Strontium..	87.63
Magnesium.....	24.32	Barium...	137.37
Calcium.....	40.07	Erbium...	167.70
<i>Family 2, Group B</i>			
Zinc.....	65.37	Mercury...	200.60
Cadmium.....	112.40		
<i>Family 3, Group A</i>			
Boron.....	11.00	Yttrium....	88.70
Aluminum.....	27.10	Lanthanum..	139.00
Scandium.....	44.10	Ytterbium..	173.50
<i>Family 3, Group B</i>			
Galium.....	69.90	Thallium...	204.00
Indium.....	114.80		
<i>Family 4, Group A</i>			
Carbon	12.005	Zirconium..	90.60
Silicon.....	28.30	Cerium.....	140.25
Titanium.....	48.10	Thorium...	232.40
<i>Family 4, Group B</i>			
Germanium.....	72.50	Lead.....	207.20
Tin.....	118.70		
<i>Family 5, Group A</i>			
Vanadium.....	51.00	Tantalum..	181.50
Columbium.....	93.10		
<i>Family 5, Group B</i>			
Nitrogen.....	14.010	Antimony..	120.20
Phosphorus.....	31.04	Bismuth...	208.00
Arsenic.....	74.96		
<i>Family 6, Group A</i>			
Chromium.....	52.00	Tungsten..	184.00
Molybdenum.....	96.00	Uranium...	238.20

TABLE 3.—*Families and groups of elements*—Continued

<i>Family 6, Group B</i>			
Oxygen.....	16.00	Selenium.....	79.20
Sulphur.....	32.06	Tellurium.....	127.50
<i>Family 7, Group A</i>			
Manganese.....	54.93		
<i>Family 7, Group B</i>			
Fluorine.....	19.00	Bromine.....	79.92
Chlorine.....	35.46	Iodine.....	126.92
<i>Family 8, Group A</i>			
Iron.....	55.84	Nickel.....	58.68
Cobalt.....	58.97		
<i>Family 8, Group B</i>			
Ruthenium.....	191.70	Palladium.....	106.70
Rhodium.....	102.90		
<i>Family 8, Group C</i>			
Osmium.....	190.90	Platinum.....	195.20
Iridium.....	193.10		

The above arrangement of the elements is not always followed as it is not easy to decide to which group some elements should be assigned. For further information regarding the periodic law, works on chemistry should be consulted. No attempt will be here made to detail fully the chemical properties of each element. Obviously some have little or no interest in connection with alloyed metals, and can be passed lightly over, or omitted entirely. In the following chapter the elements will be considered briefly in the sequence given in the foregoing table.

CHAPTER II

HISTORY, PRODUCTION METHODS, PROPERTIES, AND USES OF THE ELEMENTS

FAMILY 1, GROUP A

1. According to the arrangement of the elements adopted, family 1, group A, includes lithium, sodium, potassium, rubidium, and caesium.

LITHIUM

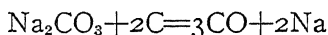
Lithium, the lightest of all metals, is a rare element of no mechanical importance. Some of its compounds (lithia especially) find extensive use in medicine. It is widely distributed in nature and is found, though always in small quantities, in several minerals (spodumene especially) and in mineral springs.

SODIUM AND POTASSIUM

These are very similar elements. Sodium occurs only in the form of salts, such as chloride in rock salt, as nitrate in Chile saltpeter, as borate in borax, as fluoride in cryolite, as sulphate in Glauber's salts, as carbonate in trona, and as silicate in feldspar. Potassium exists in ores as a silicate and sulphate, and in salts as nitrate and chlorate.

Nearly all land plants require potassium compounds for their growth, and even for their existence. These compounds are absorbed by the roots, and are converted by the plant into potassium salts of organic acids. When the plants are burned, the potassium is recovered as potassium carbonate, a salt commonly known as potash—pot ashes, hence the name. The most important mineral containing sodium is the chloride—common salt.

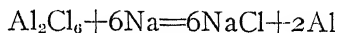
Manufacture of sodium and potassium.—Both of these metals were formerly made by treating their carbonates—potassium carbonate or sodium carbonate—with charcoal and chalk (limestone) in iron retorts; heating and collecting the metal in receivers where it condensed—a process of distillation. A mixture of 20 parts of sodium carbonate, 9 parts of crushed coal, and 3 parts of chalk were placed in an iron bottle or cylinder, and heated to a high temperature in a furnace. The neck of the cylinder was connected with an iron tube which terminated in a flat sheet-iron box outside the furnace. The sodium distilled over through the tube, and was condensed in the flat receiver to a molten condition. Provision was made for the molten sodium to flow from the condenser into a vessel containing a hydrocarbon—such as petroleum naphtha—which chilled it to a solid, and preserved it from the atmosphere. The reaction was between the oxygen of the sodium carbonate, the carbon of the charcoal, and the carbon in the carbonate, whereby new combinations were formed, resulting in the evolution of carbon monoxide, and the liberation of a portion of the sodium, probably proceeding in a limited sense according to the following equation:



The chalk was added to prevent fusion of the mass in the bottle, and by evolving a gas it assisted in carrying the liberated sodium to the receiver. The metal zinc is obtained in a similar manner.

Sodium as a reducing agent.—It is fortunate that such an element as sodium can be obtained in such a simple manner, as with this element the scientist was enabled to reduce other elements from their complex combinations, by utilizing the strong affinity of the sodium for chlorine. Thus aluminum and many other elements were first obtained in this manner. Alumina, the oxide of aluminum, could not be reduced by any means known in the early history of this element. By heating the oxide with carbon, and passing chlorine gas through the

mixture, aluminum chloride was obtained; and then by mixing the chloride with metallic sodium in proper proportions according to the equation following, aluminum was obtained:



266.76	138.00	350.76	54.00
138.00			350.76
<hr/>			<hr/>
404.76			404.76

This equation shows us that 266.76 parts of aluminum chloride will require 138 parts of metallic sodium to combine with all the chlorine and leave the metal aluminum isolated. This is about 66% aluminum chloride to 34% sodium, and the reaction would result in the production of about 87% common salt and 13% aluminum. Calculating in pounds, it required 34 lb. of sodium to produce 13 lb. of aluminum, but in practice less than this amount would be realized. The process was so expensive that the price of the metal aluminum was such that it was classed as a semi-precious metal.

The figures under the equation giving the weights are obtained from the atomic weights of the reacting substances: thus aluminum chloride consists of 2 atoms of aluminum and 6 atoms of chlorine. The atomic weight of aluminum is 27, and $27 \times 2 = 54$; the atomic weight of chlorine is 35.46, and $35.46 \times 6 = 212.76$; the atomic weight of sodium is 23, and $23 \times 6 = 138$. This gives us the weights for the reaction, and to prove if the latter is correct, we obtain the figures under the 6 atoms of salt and the 2 atoms of aluminum in the same manner. The figures for the two halves of the equation are added together as shown, and if correct, the results will be the same—in this case, 404.76. This will serve to illustrate how an element like sodium can be employed to obtain other elements which are reduced with greater difficulty. The reason why the sodium takes away the chlorine from the aluminum chloride is that it has a stronger affinity for chlorine than has aluminum. Even in cases where sodium has less affinity for chlorine than another element, it is able to take

a certain amount of the chlorine. An example of this is found in the case of barium chloride and sodium. If the latter is first alloyed with a metal of low melting point—such as tin or lead—and the mixture is kept molten, and barium chloride is scattered on the surface, the latter will be reduced, and the

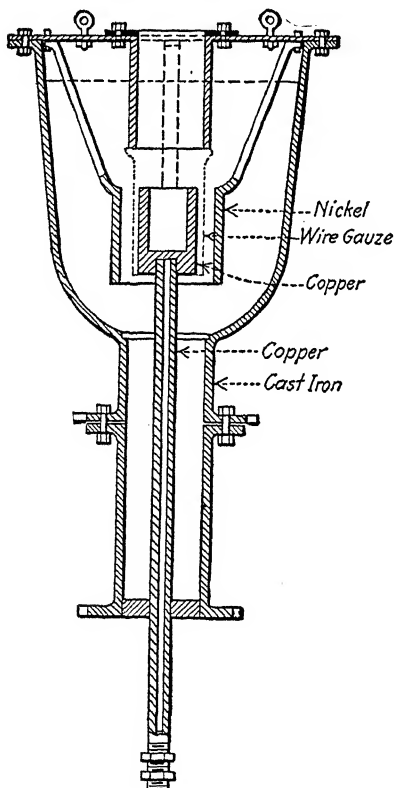


Figure 1.—Castner sodium cell.

element barium will replace some of the sodium in the tin. In this manner alloys of barium and tin containing a little over 2% barium have been prepared.

Production of sodium by electrolysis.—The modern method of obtaining sodium is by electrolysis, and a method invented by Castner was used extensively (figure 1). The process was conducted in an apparatus known as a sodium pot, which was

an iron cell containing an electrolyte—a fused mass of caustic soda, salt, and sodium carbonate. The anode was a nickel vessel suspended in the iron pot but not touching the same, and the cathode was a copper cylinder placed inside the nickel vessel without touching it, and with a cylinder of wire gauze between cathode and anode. When electricity is passed through, sodium is liberated at the cathode and is dipped out of the pot at intervals with a perforated iron ladle, and is put into ingot molds in the form of square bricks. When the brick is set—which requires longer in warm weather—the mold is opened, and the brick is removed and thrown into a drum. When the drum is filled it is taken to the storeroom where the sodium is placed under oil to prevent oxidation, until it can be placed in cans and sealed up for the market. Scrap sodium is melted in a cauldron, dipped out and poured into molds. Metallic sodium will oxidize to caustic soda, but does not take fire unless in contact with water. While the pots are working the covers are partly left off, otherwise the flame dies and the pot ceases to work properly. The gauze cylinder prevents the sodium getting into the rectangular spaces outside and inside of the pot where it would burn with explosive violence. This will happen when a hole is worn in the gauze. When the gauze touches the cathode, the pot becomes “dead” and ceases to make metal. A rod is then poked around the sides of the gauze and cathode until the contact spot is found, when a small piece of asbestos is inserted under the lug of the pot on the side opposite contact. As the pot is suspended by these lugs, the asbestos tilts it, which breaks contact and detaches the gauze, and the pot then re-commences to make metal. When the current fails, even for a second or two, the pot becomes dead and has to be taken apart, washed, and cleaned before it will work again. The ingots of sodium usually weigh $2\frac{1}{2}$ lb., and when used to make sodium peroxide, 10 lb. of ingots produce from 16 to 17 lb. of peroxide.

McNit sodium process.—Figure 2 shows the McNit process of obtaining sodium (U. S. patent, 1,214,808, February 6, 1917). In this process the electrolyte is molten sodium

chloride (common salt), and as shown by the illustration, the vessel is cylindrical with an enlarged lower part and is made of boiler iron, insulated with asbestos and lined with firebrick. It has a brick bottom through which the stem of the cathode *C* extends. The bottom of the chamber in the enlarged lower part of the vessel is surrounded by a graphite anode

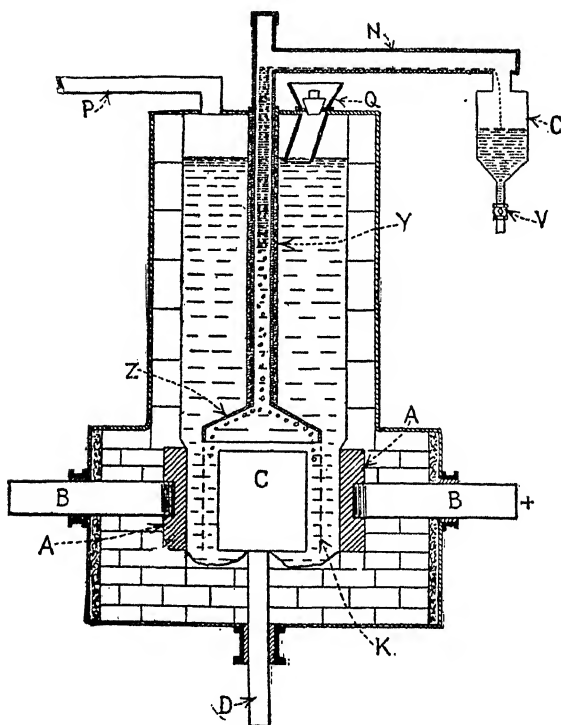


Figure 2.—McNit sodium apparatus.

A, connected to conductors *B*, extending through the sides of the vessel. A bell *Z* is suspended above the cathode *C* by means of a tubular body *Y*, which in turn is connected to the horizontal tubular arm *N*, at the end of which is suspended the small vessel *O*. At *K* is a diaphragm of perforated metal (a cylinder of gauze) which extends from the lower rim of the bell downward between the anode and cathode. When the

pot is working, chlorine gas is generated and is carried away by the tube *P*, on top of the vessel, and an aperture *Q*, provided with a cover, serves for introducing the charge into the vessel.

When in operation, the vessel is almost filled with molten salt, until a pressure of 1 lb. per square inch is reached at the zone of electrolysis. Direct electric current is conducted through the conductors *BB*, to the anode *A*, from which it flows to the cathode and through the stem of same to complete the circuit. In its passage, the current decomposes the sodium salt, with liberation of chlorine at the anode, and metallic sodium at the cathode. The chlorine passes upwards through the molten salt and escapes through the pipe *P*. The sodium liberated at the cathode rises into the bell, and collects as the electrolysis continues, and being lighter than the molten salt, it ascends the stem and floats on the surface of the electrolyte until the accumulation rises sufficiently to overflow into the horizontal pipe, from which it drips into the vessel placed to receive it. From the receiving vessel it is tapped through the valve *V* into the molds.

Characteristics of sodium and potassium.—Both of these metals are silvery-white, and soft enough to be cut with a knife. They have low melting points; potassium at 62.5° C. (114.5° F.); and sodium at 94.6° C. (204.1° F.).

Sodium can be used as a deoxidizer of copper alloys, provided it is first alloyed with a metal of low melting point like tin. An alloy of 5% sodium and 95% tin acts similarly to a phosphor-tin of the same phosphorus content, and can be usefully employed when sulphur is to be removed from the bronze.

Exposed to the air, both metals oxidize rapidly, and must therefore be preserved under a fluid containing no oxygen; or, in the case of sodium, in air-tight containers. In consequence of their peculiar properties, neither potassium nor sodium are used in their elementary state, and serve only for winning other metals from their combinations. They are also used as deoxidizing and purifying agents in the case of other metals and alloys.

Potassium is less used than sodium because it is the rarer element, and consequently is more costly. The method of making aluminum by reducing the sodium chloride was abandoned long ago, because it could not compete in price with the modern method of the electrolysis of alumina in a bath of fused chlorides and fluorides. The great bulk of the sodium now produced is consumed in the manufacture of sodium peroxide.

RUBIDIUM AND CAESIUM

Rubidium was named from the color of the lines it gives in the spectrum. The Latin, *rubidus*, deep red, suggested the name. Caesium also obtained its name from the spectrum lines which are blue, suggesting the name from *caesius*, sky blue. The chief source of rubidium compounds is the mineral lepidolite, and that of caesium is pollucite. The metals are obtained in several ways from the carbonates, hydroxides, and chlorides, which are reduced to metal by aluminum, magnesium, or calcium. They resemble potassium, take fire quickly in the air, and decompose water. They are rare elements, and not likely to be used for alloying purposes.

FAMILY 1, GROUP B

2. The metals of group B, family 1 are copper, silver, and gold. These three well-known elements are classed with the heavy metals, and are all good conductors of electricity. Although they are classed together, there is considerable difference in their chemical properties.

COPPER

Occurrence of copper.—This metal gets its name from the island of Cyprus, where it was mined extensively. It is found and mined in nearly all countries, especially in North and South America. It occurs native—that is, in the metallic state in large masses. Most of the world's supply is obtained from ores. The richest ores are the oxides—ruby copper or

cuprous oxide (Cu_2O), and cupric oxide (CuO). Cuprous oxide is also known as cuprite or red copper ore. Some of the ores of copper are of green, red, or blue in color. Thus malachite, the carbonate ($\text{CuCO}_3, \text{Cu}(\text{OH})_2$), is a green beautifully veined stone which is often used for ornamental purposes; while azurite ($2\text{CuCO}_3, \text{Cu}(\text{OH})_2$), has a deep blue color. Some ores of copper contain sulphur, such as chalcocite, the sulphide (Cu_2S); and copper pyrite, the sulphide of copper and iron ($\text{Cu}_2\text{S} \cdot \text{Fe}_2\text{S}_3$). The sulphide ores are more difficult to reduce to metal than the oxides. The oxides and carbonates are easily reduced by heating in contact with carbon (coke), and a flux (limestone), to remove the impurities. The most common ore is the sulphide—either of copper, or of copper combined with iron—and the treatment of these ores to extract the metal is complex. What are known as the “porphyry” or “disseminated” copper deposits in Arizona, Nevada, New Mexico, Utah, and Chile, contribute most of the world’s copper. The mineral is chalcocite, the sulphide.

Treatment of copper ores.—Most of the ores recovered from the 29 mines of the Anaconda Copper Mining Co. at Butte, Montana, are sulphide ores. The average copper content of the ores is about 3%, therefore the first work is to concentrate the ores, which raises the copper content to 8%. Next the sulphur must be removed by roasting or smelting according to the size of the ore. The fine ore and concentrate is roasted, whereby 80% of the sulphur is eliminated, and then smelted in reverberatory furnaces; and the coarse ore is smelted in blast-furnaces, in which process 60% of the sulphur is removed. The furnace product from both fines and coarse ore is matte, which contains about 40% copper. This matte is refined in converters (figure 4), by blowing air through it while molten. The metal from the converters is an impure copper which is tapped for refining into smaller reverberatory furnaces than those used for reducing ore and concentrate. At some plants they are heated by pulverized coal. In the refining furnace, the impurities—iron and sul-

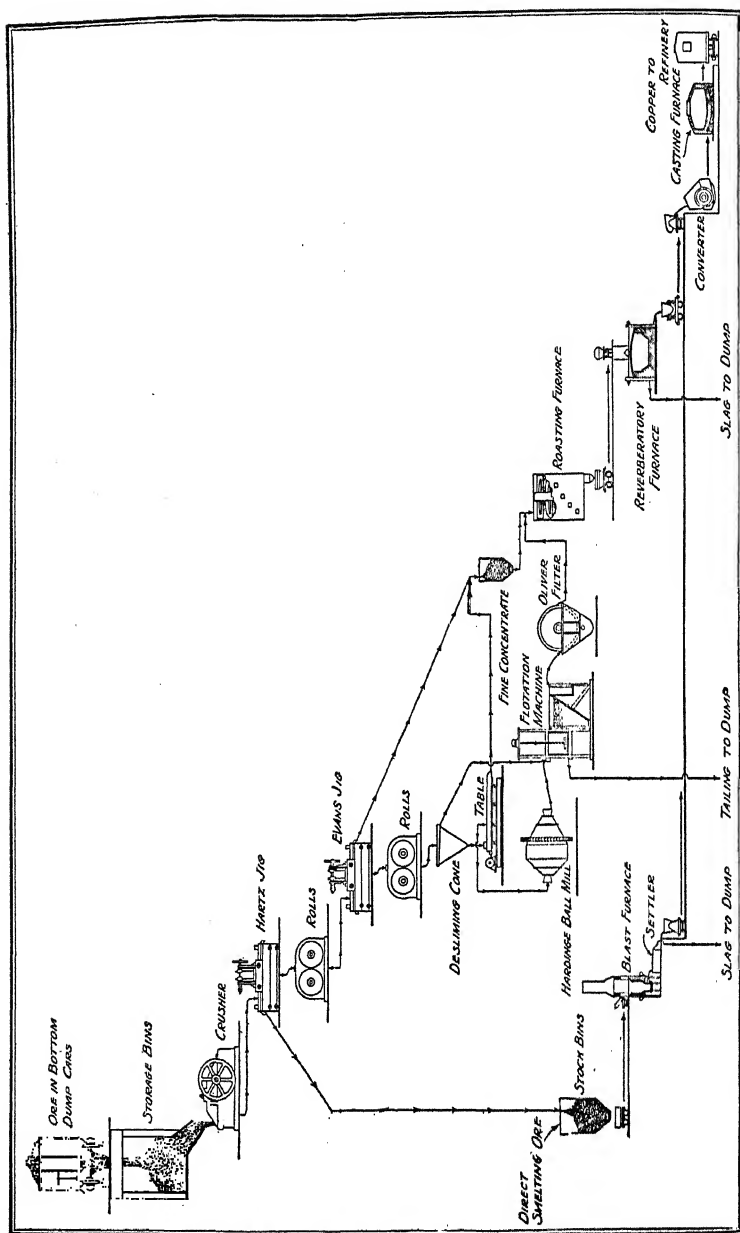


Figure 3.—Flow of material from ore-cars to railroad cars at Butte and Anaconda, Montana.

phur—which were not entirely removed by the previous treatment, are oxidized by blowing air into the copper, through an iron pipe. The pipe is pushed into the molten copper, and the air at 16-lb. pressure boils through the metal, burning out the iron and sulphur, the former as a slag and the latter goes off with the furnace gases. Some of the copper is oxidized, and the oxide dissolves in the molten copper, and

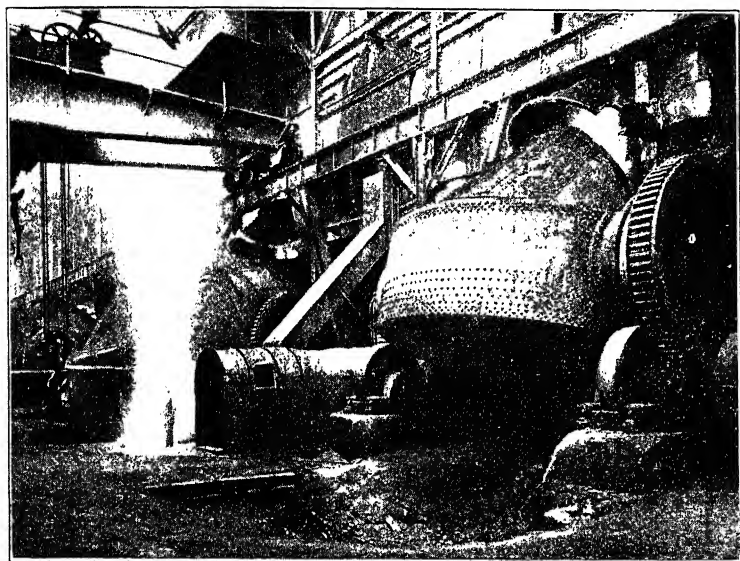


Figure 4.—Converters at Anaconda reduction works, Montana.

is later reduced to the metallic condition by the process of poling (green poles held under the surface). When the copper has been brought to the proper condition of purity as determined by the "pitch," it is run into flat slabs with two horns on opposite corners of one end. These slabs are known as anodes, and contain all of the silver and gold of the original ores, as well as other metallic impurities not removed by the processes through which the copper has passed. Figure 3, reproduced by courtesy of the Anaconda Copper Mining Co., shows at a glance all the operations required from ore to finished product. For further details the reader is referred

to "Copper: from Mine to Finished Product," a 58-page booklet published gratis by this company.

Electrolytic refining of copper.—The anodes are shipped to the electrolytic refinery, where the copper is plated off the anodes onto cathodes. The latter are thin starting sheets made by stripping off a plated deposit from what are known as "starting blanks"—sheets of hard polished copper $\frac{1}{8}$ -inch thick—which are used continuously for making starting sheets. These latter are 30 inches wide, 37 inches long, and weigh about 8 lb. At the end of 10 days they will have increased in weight to about 135 lb. each, when they are removed from the vats, carefully washed, and are melted in refining furnaces of 225 to 250 tons capacity. In the refining furnaces the copper cathodes again go through the process of oxidation by air, after which the copper is again poled to reduce the oxide to metal.

From this last refining furnace the copper is cast into the various commercial forms of ingot, ingot bar, wire bar, slab, billet, square cake, and round cake. A representative analysis of refined electrolytic copper, as published by the Anaconda company, is as follows:

Analysis of refined electrolytic copper (N. E. C. Cooper)

	Per cent
Copper.....	99.94 to 99.97
Oxygen.....	0.02 to 0.05
Silver.....	0.00100
Gold.....	0.00001
Sulphur.....	0.00300
Iron.....	0.00250
Nickel.....	0.00150
Arsenic.....	0.00150
Antimony.....	0.00200

The sum of the metallic impurities is slightly over 0.01%.

Oxide in copper.—The microphotographs (figures 5, 6, and 7), show copper in various stages of purity. Figure 5 is a forged copper made from a casting deoxidized by the addition of an alloy of about 7% silicon, 5% calcium, and 88% copper. It will be noted that only traces of oxide are shown. In figure 6 is shown the structure of a copper at

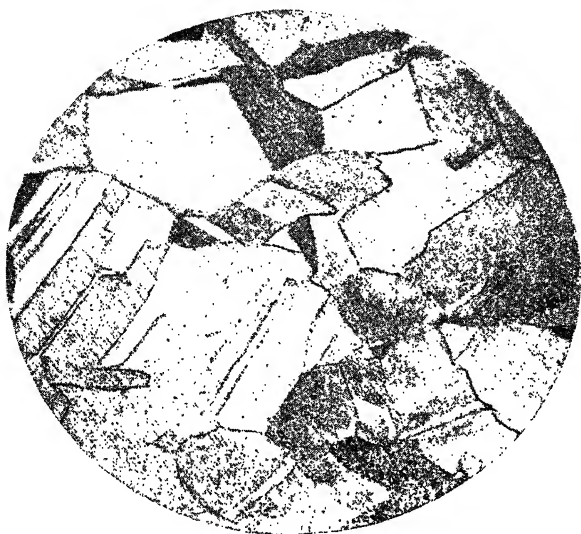


Figure 5.—High conductivity forged copper. Some twinned crystals; only traces of oxide. ($\times 100$.) Etched with ammonium hydroxide and hydrogen peroxide.

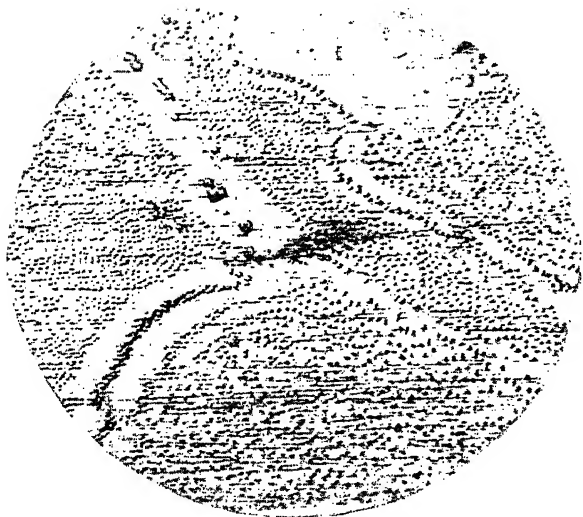


Figure 6.—Pure copper from Raritan refinery. Shows spots of nearly pure $\text{Cu} + \text{Cu}_2\text{O}$ eutectic. ($\times 400$.) Unetched.

tough pitch. The dots are oxide. Figure 7 shows a copper badly oxidized. It contains a relatively large amount of oxide, and it will be realized that in making castings of copper, considerably more deoxidizer would be required in the case of the copper shown in figure 7, than in the case of figure 5. The use of a copper like in figure 6, in place of one like in figure 5, would mean failure to get sound castings, unless it was known to contain excess oxide, and was treated accord-

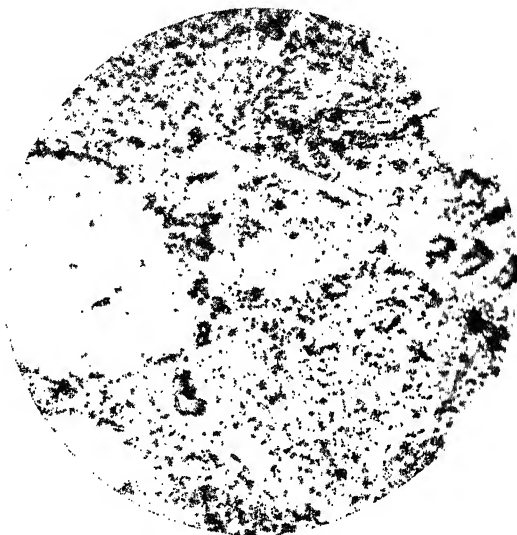


Figure 7.—Oxidized copper. Shows eutectic of $\text{Cu} + \text{Cu}_2\text{O}$, the latter being the small round spots. ($\times 700$.) Etched with ammonium hydroxide and hydrogen peroxide.

ingly. It is doubtful if the addition of a metallic deoxidizing agent would work in the case of figure 7, to ensure sound castings; at any rate it would require considerably more of it than in the case of figure 5. If the condition of the copper was not known, and it was treated the same as that of figure 5 had always been, and a poor result obtained, naturally the foundryman would consider the deoxidizer at fault. This has happened many times and resulted in loss of money due to wasters, and to loss of faith in the deoxidizer, which unde-

servedly got the blame. During a foundry run making important copper castings, if a new consignment of copper has to be used, it will usually pay to make a small separate test heat to determine if there is any difference in oxide in the new supply of copper.

Shapes of copper ingots.—The different shapes of com-

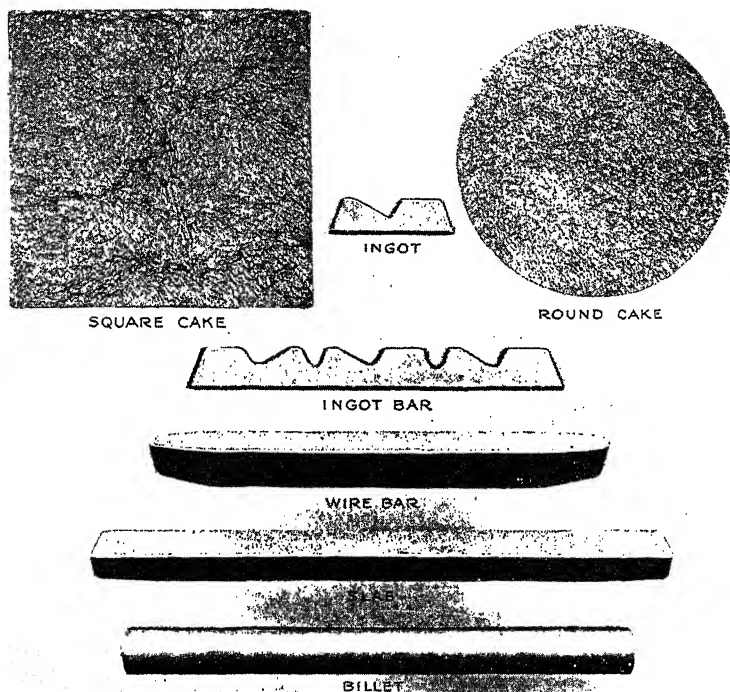


Figure 8.—Shapes of refined copper made by the Anaconda Copper Mining Co., at Raritan, New Jersey.

mercial copper are made with a view of meeting the special requirements of each industry using the metal. Thus the small ingots are primarily used for crucible melting; the long ingots or ingot bars are merely three ingots in a bar with deep notches between to be readily broken into ingots, and are made in this shape for convenience in transportation; wire bars are long, straight bars, with pointed ends to facilitate

passage through the first set of rolls in the production of wire; slabs and square cakes are used for rolling into sheet copper; circular cakes are for rolling and drawing into large, seamless, cylindrical shapes, such as hot-water heaters and tanks; billets are round bars, and are used for the manufacture of seamless copper tubing of all sizes, also for shell bands, and vary from 3 to 8 inches in diameter. The various shapes of copper as turned out by the Anaconda company are shown in figure 8.

In producing the various copper shapes, either iron or copper molds can be used, but the latter gives the best results. The ingot molds are made by molding a pattern in sand.

GRADES OF COPPER

The following grades of copper are commercially known:

Lake copper.—This is metal from the mines of the Lake Superior district (Michigan). The standard range of conductivity is 99.50%.

Electrolytic copper.—This is metal refined by the electrolytic process, and running 99.93% and upwards for cathodes, conductivity to 102%.

Casting copper.—Metal containing 99 to 99.75% copper, made from ore and scrap. Used for casting purposes.

Best selected copper.—A British copper averaging 99.75% fine. Largely used in the British brass trades.

Tough copper.—British copper, largely used for casting, rolling, and drawing, runs about 99.25% copper.

Chile bars.—Copper smelted in Chile running 95 to 99% pure, and in some cases carrying bullion (gold and silver).

Standard copper.—Practically anything running from 96% copper upwards; dealt in on London Metal Exchange.

Matte.—A semi-metallic furnace product made from ores, usually carrying from 25 to 55% copper. An intermediate product between the ore and the finished copper.

GRADES OF SCRAP COPPER

Secondary copper, or copper scrap, according to the Waste Trade Specifications for scrap metal, shall be in the following forms:

Heavy copper (code word, Base).—This material shall consist of copper, not less than $\frac{1}{16}$ inch thick, and may include trolley wire, heavy field wire, and heavy armature wire, which is not tangled; also new copper clippings and punchings, untinned and clean; also copper segments which are clean.

No. 1 copper wire (code word, Clan).—This material shall consist of clean untinned copper wire, not smaller than No. 16, B. & S. wire gage. Must be free from burnt copper wire which is brittle, and from all foreign substances.

No. 2 copper wire (code word, Dale).—To consist of miscellaneous copper wire, such as of necessity would be taken out of the heavy copper and the No. 1 copper wire. It must be free of hair wire, and burnt wire, which is brittle.

Light copper (code word, Edge).—Shall consist of the bottoms of kettles and boilers, bathtub linings, hair wire, burnt copper wire which is brittle; copper and similar copper free of visible iron; brass, lead, and solder connections; old electrotpe shells, and free of excessive paint, tar, and scale.

SPECIFICATIONS FOR COPPER

The specifications of the American Society for Testing Materials for electrolytic copper wire bars, cakes, slabs, billets, ingot bars, and ingots, are as follows:

1. All wire bars, cakes, slabs, and billets shall be stamped with the makers' brand and furnace charge mark. Ingots and ingot bars shall have a brand stamped or cast in, but need have no furnace charge mark.

2. The refiner shall arrange carloads or lots so that as far as possible each shall contain pieces from but one furnace charge, in order to facilitate testing by the user.

(a) Metal content.—The copper in all shapes shall have a purity of at least 99.880%, as determined by electrolytic assay, silver being counted as copper.

(b) Resistivity.—All wire bars shall have a resistivity not to exceed 0.15535 international ohm per metergram at 20° C. (68° F.) (annealed). All ingot and ingot bars shall have a resistivity not to exceed 0.15694 international ohm per metergram at 20° C. (68° F.) (annealed).

3. Cakes, slabs, and billets shall come under the ingot classification, except when specified for electrical use at time of purchase, in which case wire-bar classification shall apply.

4. Wire bars, cakes, slabs, and billets shall be substantially free from shrink holes, cold sets, pits, sloppy edges, concave tops, and similar defects in set, or casting. This clause shall not apply to ingots or ingot bars, in which case physical defects are of no consequence.

5. Five per cent variation in weight or ¼-inch variation in any dimension from the refiner's list or purchaser's specified size shall be considered good delivery; provided, however, that wire bars may vary in length 1% from the listed or specified length, and cakes 3% from the listed or specified size in any dimension greater than 8 inches. The weight of ingot and ingot bar copper shall not exceed that specified by more than 10%, but otherwise, its variation is not important.

6. Claims against quality shall be considered as follows:

(a) Resistivity by furnace charges ingot lots, or ingot bar lots.

(b) Metal contents by furnace charges ingots lots, or ingot bar lots.

(c) Physical defects by individual pieces.

(d) Variation in weights or dimensions by individual pieces.

7. The refiner's representative shall inspect all pieces where physical defects or variation in weight or dimension are claimed. If agreement is not reached, the question of fact shall be submitted to a mutually agreeable umpire, whose decision shall be final.

In a question of metal contents, each party shall select a sample of two pieces. These shall be drilled in the presence of both parties; several holes approximately ½ inch in diameter being drilled completely through each piece, scale from set shall be rejected. No lubricant shall be used, and drilling shall not be forced sufficiently to cause oxidation of chips. The resulting samples shall be cut up, mixed, and separated into three parts, each of which shall be placed

in a sealed package, one for each party, and one for the umpire if necessary. Each party shall make an analysis, and if the results do not establish or dismiss the claim to the satisfaction of both parties, the third sample shall be submitted to a mutually agreeable umpire, who shall determine the question of fact, and whose determination shall be final.

In a question of resistivity, each party shall select two samples, and in the presence of both parties these shall be rolled hot and drawn cold, into wire of 0.080 inch in diameter approximately, which shall be annealed at approximately 500° C. Three samples shall be cut from each coil and the same procedure followed as described in the previous paragraph.

8. The expenses of the shipper's representative and of the umpire shall be paid by the loser, or divided in proportion to the concession made in case of compromise. In case of rejection being established, the damage shall be limited to payment of freight both ways by the refiner for substitution of an equivalent weight of copper, meeting these specifications.

The properties of copper.—The physical and mechanical properties of copper are as follows:

Physical properties of copper

Atomic weight.....	63.57
Principal valence.....	1 or 2
Specific gravity.....	8.91
Specific heat at 0° C.....	0.0936
Melting point, ° C. and ° F.....	1083 and 1981
Boiling point, ° C. and ° F.....	2310 and 4180
Linear coefficient of expansion, per ° C.....	0.000017
Latent heat of fusion, calories.....	43.3
Thermal conductivity (silver as 100).....	73.6
Vapor tension at 1120° C., millimeters.....	0.28
Heat in solid at melting point, calories.....	118.7
Heat in liquid at melting point, calories.....	162.0
Ultimate tensile strength, lb. per sq. in.....	17,000 to 20,000
Yield point, lb. per sq. in.....	6,000 to 9,000
Elongation in 2 inches, %.....	40 to 50
Reduction of area, %.....	60 to 70
Brinell hardness number, 500 kg. load for 30 sec.....	30 to 40
Patternmakers' allowance for shrinkage, inch per foot.....	0.25
Weight per cubic inch, lb.....	0.32
Compression, elastic limit, lb. per sq. in.....	4000

The above physical properties were obtained on cast copper using molding sand molds. The copper was deoxidized with an alloy of silico-calcium copper, using 0.75%.

SILVER

Sources and methods of recovery.—This element is a white metal, very malleable and ductile. It occurs in the native state, associated with more or less gold, and as an ore combined with sulphur and chlorine. Silver glance is a sulphide of silver, and horn silver a chloride of silver. Copper, lead, and zinc ores frequently contain silver; in fact, of the world's production of silver, about 70% is recovered as a by-product from the treatment of these base-metal ores. The remaining 30% of the silver is extracted from what are termed straight silver ores. Such ores occur in veins, generally in eruptive rocks, such as andesite, rhyolite, trachyte, and the like; and the silver is extracted by crushing the ores very fine and dissolving out the metal by means of a solution of sodium cyanide, and precipitating the silver on finely divided zinc or aluminum.

Where the silver is obtained from galena, the lead sulphide, the ore is either first concentrated and the concentrate is roasted and smelted; or all of the ore is roasted and smelted, this depending upon the grade of the ore. The problem of the metallurgist is to separate the lead, silver, and sulphur.

The lead resulting from the process of reduction contains the silver. Sometimes the amount may be very small, about 0.15%, but it is possible to extract the silver profitably when it exists in the lead to the amount of only 0.01% (less than 3 oz. to the ton). The method practiced by the International Lead Refining Co., at East Chicago, Indiana, is to melt the lead bullion, as it is termed, in three softening furnaces, of 220 tons capacity each. In these furnaces the antimony and arsenic are removed, as these metals make the lead hard, and by their removal the lead is softened. From the softening furnaces the lead is run into the desilvering kettles (figure 9), where the silver is removed by the Parke's process. The principle of this process is that when argentiferous lead is thoroughly stirred with a small proportion of zinc, and the metals are allowed to cool slowly, the zinc separates from the lead and rises to the surface, carrying with it most of the

silver in the form of a crust. In other words, the silver has greater affinity for the zinc than the lead. This crust is an alloy of lead, silver, zinc, and any gold present, and melts at a higher temperature than the lead. It is skimmed off into pneumatic presses which squeeze out the excess of lead, leaving a dry alloy containing about 3000 oz. of silver per ton, together with the gold. Most of the zinc is recovered and used

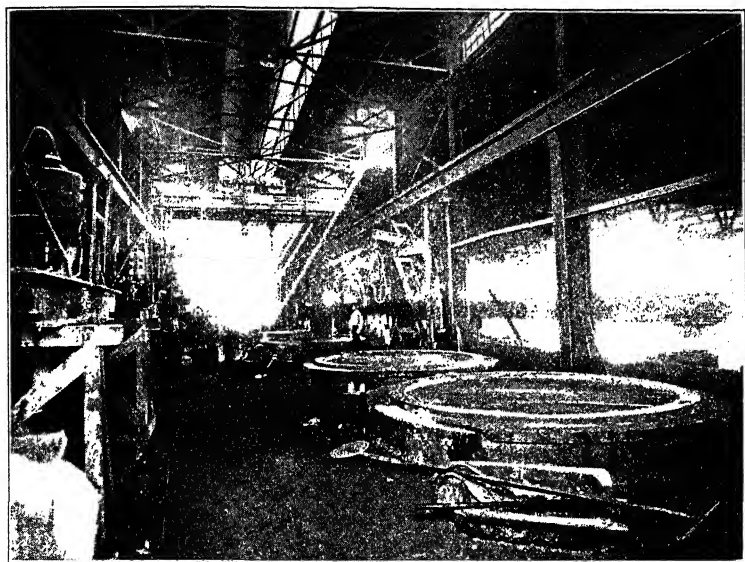


Figure 9.—Desilvering kettles—International Lead Refining Co., East Chicago, Indiana.

again. The silver is recovered by first melting the silver-zinc-lead alloy in graphite crucibles or retorts, in which the zinc is distilled off and recovered. The metal remaining in the retorts is cupelled to remove the lead and copper, leaving the silver and gold, which has to be separated by further treatment, known as parting. Any lead left in the kettles is further treated in a refining furnace, and then cast into pig as shown in figure 10.

Another process for removing the silver from lead is known as the Pattinson process. This depends on the fact

that when molten argentiferous lead is allowed to cool slowly, crystals of pure lead are first deposited from the liquid mixture. The lead is melted in iron pots, then if water is sprinkled on it, the surface lead crystallizes and may be skimmed off by using a perforated ladle. By continuing this process, part of the lead is obtained which is much poorer in silver than the original metal. When about two-thirds of the lead has been

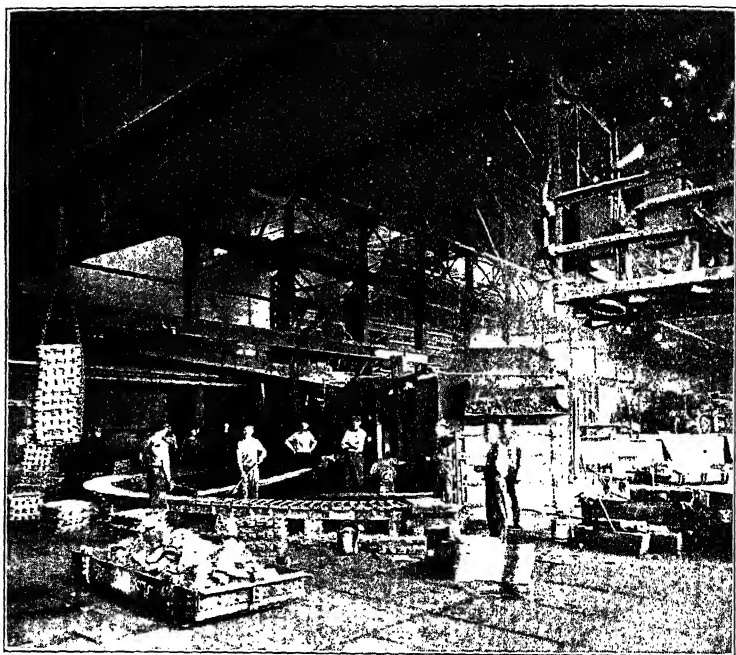


Figure 10.—Casting refined lead—International Lead Refining Co., East Chicago, Indiana.

removed in the form of crystals, the remaining metal has been enriched to nearly twice the content of silver in the original metal. By further treatment the silver content is brought up to about 1% (360 oz. per ton) and the silver is obtained by oxidizing the lead to litharge, which latter is easily reduced back to lead.

When silver is carried in copper ores, say from 2 to 8 oz. per ton, it passes through all the treatment processes with the

copper, and is finally recovered, with the gold, as a sludge or mud at the bottom of the electrolytic tanks in the refinery. This by-product is then dried, and melted, yielding the silver and gold, called doré bullion.

The term doré bullion is not restricted to that recovered at smelters, and is frequently applied to silver-gold bullion extracted from ores by cyanidation; but the metals are generally separated at the mint.

Parting doré bullion (silver and gold) at the refinery of the Bunker Hill & Sullivan smelter at Kellogg, Idaho, was described by T. A. Rickard.* This bullion is the result of cupelling lead. The 500-oz. bars of doré bullion, in charges of 10,000 oz., are parted in cast-iron kettles by means of 66° Bé. sulphuric acid. The silver is dissolved, and the resulting silver-sulphate solution is drawn into lead-lined vats. Copper bars are suspended in these vats by means of "corrosiron" hooks, and steam is introduced to make the solution boil. The silver is precipitated on the copper, which in turn goes into solution as sulphate. The silver is deposited as cement silver, which is filtered, washed in boiling water, dried, and melted in a Monarch double-chamber oil-fired tilting furnace. The resulting silver is 999 fine. For 1000 oz. of silver produced, 125 lb. of acid and 21 lb. of copper is used. The insoluble residue in the kettle contains the gold in the form of a brown powder. It is boiled to remove any sulphates, then melted in a graphite crucible. The copper solution is partly evaporated to cause the copper sulphate to crystallize, and the crystals are re-dissolved in water and again crystallized on strips of lead in another lead-lined vat, and is then ready for the market—to be used in flotation mills using a selective process, or for spraying trees.

Some details of melting silver will be found under Chapter XXI, Alloys of the Precious Metals.

The principal uses of silver are for utensils, coins, and ornaments, and for coating (plating) other metals and glass. Some of the properties of silver are as under:

* *Min. Sci. Press*, vol. 122, 1921, p. 58.

Physical properties of silver

Atomic weight.....	107.88
Principal valence.....	1
Specific gravity.....	10.53
Specific heat at 0° C.....	0.0559
Melting point, ° C. and ° F.....	961.5 and 1762
Boiling point, ° C. and ° F.....	1955 and 3551
Linear coefficient of expansion.....	0.00001921
Thermal conductivity.....	100 (silver is the standard)
Electrical conductivity.....	100 (silver is the standard)

GOLD

This element is so chemically inactive that it is mostly found in the native condition, although often containing silver. It is widely distributed throughout the world, but its deposition in workable quantities is more or less limited, depending upon local economic conditions. If gold is found in deposits of sand and gravel, and other factors are suitable, material worth only a few cents per cubic yard is profitable; while if the gold is in ore in a vein, it may not be profitable under \$3 to \$10 per ton. Of the world's production, about 90% comes from the treatment of straight gold ores, the remainder being copper and lead ores; although gold occurs with many other minerals, some in payable quantities. Gold ores are crushed fine, and the metal is extracted therefrom mostly by catching it with quicksilver and dissolving it in a solution of sodium cyanide; and sometimes by concentrating the ore, and getting the gold from the concentrate by cyanidation or smelting. In general, the process simulates that of recovering silver.

Gold is a yellow metal, soft and malleable, and can be beaten into sheets so thin as to be transparent, the transmitted light being green. It is used for coins, jewelry, ornaments, and dental purposes. Being a very soft metal it is usually alloyed with other metals, principally copper. It is not attacked by hydrochloric, nitric, or sulphuric acids, although it is dissolved by a mixture of 3 parts of hydrochloric and 1 part of nitric acid, known as aqua regia. Some of the properties of gold follow:

Physical properties of gold

Atomic weight.....	197.2
Principal valence.....	1 or 3
Specific gravity.....	19.32
Specific heat at 0°.....	0.0316
Melting point, ° C. and ° F.....	1062 and 1943
Boiling point, ° C. and ° F.....	2500 and 4532
Linear coefficient of expansion.....	0.00001470
Thermal conductivity.....	53.2 (silver, 100)
Electrical conductivity.....	76.7 (silver, 100)

FAMILY 2, GROUP A

3. The elements comprised in family 2, group A, are glucinium, magnesium, calcium, strontium, barium and usually, erbium.

GLUCINIUM

Glucinium is more frequently known as beryllium, the most common mineral source of which is beryl. According to Prof. C. James of New Hampshire College, Durham, New Hampshire, it is an element which is by no means uncommon, and one that might have important industrial uses if produced in sufficient quantity, and at a reasonable price. Many glucinium minerals are used in jewelry—thus the emerald is a variety of beryl. The element is not well known, although it appears to possess possibilities from an alloying standpoint. It appears to have considerable similarity to aluminum, and alloys with copper in a manner similar to that metal.

MAGNESIUM

Sources of magnesium.—This element, on account of its great chemical activity, is always found in a state of combination, and never occurs in the metallic form. Its ores are widely distributed and are of considerable variety; such as the hydrate, carbonate, chloride, bromide, sulphate, phosphate, and nitrate. In combination with silica, it is also found as a component of a number of naturally occurring minerals, as for example, hornblende, augite, talc, soapstone, asbestos, and others. Magnesium is also found in mineral waters. Sea water

contains considerable quantities of the sulphate and chloride, and magnesium salts are also found associated with sodium chloride and potassium chloride in various parts of the world.

The great English chemist Sir Humphry Davy is usually credited with having first isolated the metal magnesium in the year 1808, but we are informed he used potassium vapor to reduce white-hot magnesia (the oxide of magnesium), so it is exceedingly unlikely he succeeded in obtaining the metal itself. It would appear that the credit for obtaining the metal first should go to Bussy, the French chemist, who in 1830, worked with potassium on the anhydrous chloride of magnesium.

Old process of obtaining magnesium.—The early method was similar to that adopted in the case of aluminum and other metals reducible with difficulty, namely, the reduction of the anhydrous chloride by the metal sodium, which latter metal, as before mentioned, could be obtained by a process of distillation with carbon. On a commercial scale, magnesium was first produced by Sonstadt in 1864, who organized the Magnesium Metal Co. of Manchester, England. The first step in the process of manufacture was to prepare the anhydrous chloride of magnesium, and the second step was to reduce the chloride by sodium, using an iron crucible. The proportions of magnesium chloride and sodium were 5 to 1. The sodium was cut into small pieces, mixed with the chloride, and placed in the crucible, which was then heated to redness to start the reaction, the chlorine leaving the magnesium for the sodium, forming sodium chloride or common salt and the metal magnesium. The latter was in the shape of nuggets of various sizes which were recovered from the fused salt after cooling, by breaking it up and picking out the magnesium. The latter metal was in a crude state and had to be purified by a process of melting and distilling.

Improved process of obtaining magnesium.—The above method of obtaining magnesium has long been superseded by other processes, one of which is the electrolytic. Attempts have been made to obtain magnesium in a manner similar to that followed in the case of zinc, namely, by distillation, as

illustrated by figure 11, which shows an apparatus devised by W. F. Bleeker and W. L. Morrison (U. S. patent No. 1,311,378). By this method, magnesian ores—such as magnesite or dolomite—are calcined in a reverberatory furnace *A* and then mixed with a reducing agent—such as crushed silicon or powdered aluminum—to remove the combined oxygen, and heated to a high temperature in the electric furnace *B*. Here the magnesium is liberated in the form of a vapor which is condensed in the adjoining chamber *C*, either

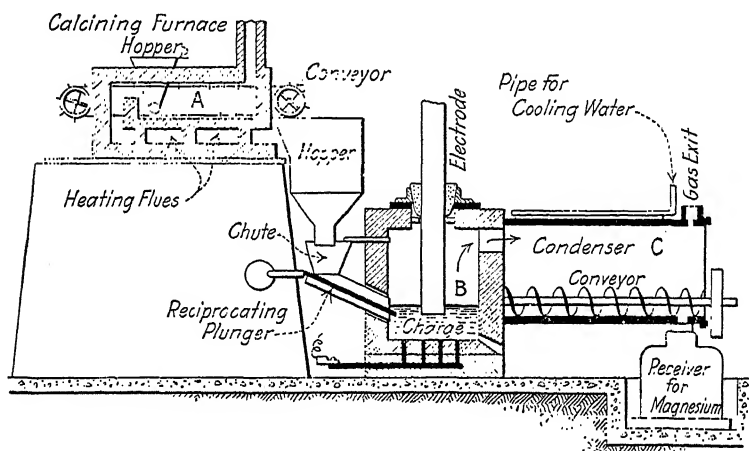


Figure 11.—Apparatus for producing magnesium by distillation.

as a powder or in agglomerated form. This process appears to be a step backward, as another element has to be sacrificed to obtain the magnesium, just as in the original process. The cost of the magnesium made by this process would be dependent upon that of the silicon or aluminum used, and unless carbon could be used as the reducing agent, the electrolytic process would appear to possess advantages.

Electrolytic production of magnesium.—In producing magnesium electrolytically, anhydrous magnesium chloride is used by one modern process, and patents cover both the method of preparing the chloride and its reduction to metal. This improved method of producing anhydrous magnesium chloride

was patented by Edgar A. Ashcroft of London, England (U. S. patent No. 1,359,652), and consists of dehydrating the hydrated chloride by passing over it large volumes of heated air until fusion occurs, when the salt is retorted at a temperature of 150 to 650° C., while dry chlorine gas is passed over it. The metal is obtained from the chloride by electrolysis, using anodes of graphite and cathodes of a lead-magnesium alloy in a twin-cell apparatus. The anodes of the primary cell are of graphite, the cathodes of a molten magnesium-lead alloy, and the electrolyte is fused anhydrous magnesium chloride. The anode of the secondary cell is formed of magnesium-lead alloy from the primary cell; the cathodes are of iron, and the metallic magnesium gathers at the iron cathodes and is removed periodically. The primary cell voltage varies from 4 to 6 volts, that of the secondary cell from 1 to 2.5 volts. The temperature of the cells is about 750° C., and a current efficiency of about 92.5% is claimed. The primary cells evolve chlorine gas, which is collected and absorbed by a watery emulsion of lightly calcined dolomite, forming magnesium chlorate and magnesium chloride, which, being crystallized and dehydrated by the patented method, forms anhydrous magnesium chloride, the material of the electrolyte. As magnesium chloride is necessary to the production of magnesium, the efforts of numbers of inventors have been directed towards cheapening the methods of obtaining this chemical.

Commercial magnesium.—The magnesium produced in the United States is often procurable in the shape of sticks, about 1¼ inches in diameter, crudely cast. The German-made magnesium is in the shape of extruded sticks, about ¾ inch square, and is a superior looking article. Alloys of magnesium with other metals are easily made, as is shown in Chapter XXIV.

Production.—Magnesium is essentially a modern metal. Prior to 1914 its production was almost entirely by Germany, although the manufacture of this metal was begun as early as 1864, both at Boston, Massachusetts, and Manchester, England. As magnesium is one of the metals essential to the conduct of

modern warfare, its production in the United States during the World War was so stimulated that its history reads like a romance. According to the report of the U. S. Geological Survey, the output of magnesium in 1915 was 87,000 lb.; but in 1918 this had increased to 284,188 lb., an increase of nearly 225% in three years, and 145% over the previous year. About 40% of the output in 1918 was in the powdered form for use in star shells and war photography. The peace-time uses of the metal are always extending, and it is now largely used in casting parts for internal-combustion engines, such as connecting rods, and pistons.

Magnesium has the following physical properties:

Physical properties of magnesium

Atomic weight.....	24.32
Specific gravity.....	1.74
Specific heat at 0° C.....	0.2456
Melting point, °C and °F.....	651 and 1204
Boiling point, °C. and °F.....	1120 and 2048
Linear coefficient of expansion.....	0.00002924
Tensile strength, cast, lb. (about).....	20,000
Tensile strength, rolled, lb. (about).....	35,000
Electrical conductivity.....	about 40% that of silver

CALCIUM

Metals of the alkaline earths.—Calcium, strontium, and barium are known as the metals of the alkaline earths. Calcium occurs in limestone, gypsum, and several other minerals; strontium occurs in the form of the sulphate (SrSO_4), known as celestite, also as the carbonate (SrCO_3), known as strontianite. Barium occurs in the same forms of combination as strontium, as the carbonate, (BaCO_3) known as witherite, and the sulphate (BaSO_4) known as barytes (barite) or heavy spar. It will be noted by turning to the table of atomic weights that the three elements are progressively heavier from calcium to barium. The difficulty of obtaining the metals is in direct proportion to their weight; thus calcium is obtained comparatively easily by electrolysis, strontium with more difficulty, while barium oxidizes so energetically that it is very difficult to procure in the metallic form.

Calcium is coming into extensive use as a deoxidizing agent. In the form of calcium silicide it is employed in the purification of steel; and in alloy with copper, silicon, and magnesium it is being used with success in deoxidizing copper in the production of castings possessing high electrical conductivity. Calcium, either alone or in connection with strontium, barium, and magnesium, is also used extensively for hardening lead and other metals of low fusing temperature, and these hardened metals are used for bearings, in the same manner as the babbitts.

Strontium and barium are also coming into service as cleansers of other metals and alloys. While both barium and strontium are difficult to obtain in the metallic state, they are easily obtained in alloy with metals like tin and lead.

Alloys of both strontium and barium with tin and lead can be obtained commercially. The best proportion of the two metals for use as deoxidizers is 5%, with a tin content of 95%. This alloy is stable, and is used like phosphor-tin in purifying alloys of copper, tin, lead, and zinc.

ERBIUM

This element is supposed to resemble aluminum in some respects. It occurs in some rare minerals found in Greenland and Sweden.

FAMILY 2, GROUP B

4. Group B of family 2 contains the well-known metals, zinc, cadmium, and mercury.

ZINC

Zinc deposits are found in many countries, rarely carrying the metal alone, but mostly with lead and silver. Most of the metal is recovered from blende, the sulphide (ZnS); although a good deal comes from the silicate (calamine) and the carbonate (smithsonite). The metallurgy of zinc is as difficult as the properties of the metal are peculiar.

Although they were accustomed to use its ores in the manufacture of brass, the ancients were not familiar with zinc in its metallic state. The alchemist Paracelsus in 1541 makes mention of metallic zinc, but it was doubtless known before his time, and was probably discovered by Albertus Magnus, who called it *marchasita aurea*. It became a regular article of manufacture in Germany in about 1720, and in England 15 or 20 years later. It has been regularly manufactured in the United States since 1850, first in New Jersey, and later in a number of other States.

Properties of zinc.—Metallic zinc is a bluish-white metal known to the trade as spelter. Its properties are rather peculiar, and as it plays an important part in the manufacture of alloys, it will have to be considered at some length. Zinc is hard and brittle, and when fractured, exhibits a highly crystalline structure. It is little altered by exposure to the air, becoming very slowly coated with a permanent and impenetrable film—a basic carbonate—which renders it valuable for sheathing and for work exposed to the weather. Zinc can be cast, and makes good architectural ornaments. The castings made at a high temperature are brittle and crystalline, but when cast at near the melting point they are comparatively malleable. Zinc is hardened by working and should be annealed occasionally.

At ordinary temperatures, zinc shows a considerable degree of brittleness, and if a piece of sheet zinc be bent back and forth several times it soon breaks; but by heating it to between 230 and 302° F., it acquires a considerable degree of ductility, and can be rolled out into thin sheets. At a still higher temperature it again becomes brittle, and when heated at 392° F., can readily be reduced to a powder. Its specific gravity varies with its physical condition. Zinc melts at 786.9° F. By heating the fused metal a little above its melting point with the admission of air, it ignites, and burns with a bright, white flame to a very spongy, pure, white powder, forming the oxide known under the name of “zinc white.” This is employed largely as a pigment and as a filler in rubber, especially automobile tires. It

is chiefly valued for its permanency, as it is not blackened by exposure to sulphuretted hydrogen like white lead. At a white heat, zinc boils and can be distilled.

Recovery of zinc from ores.—Zinc was formerly exclusively obtained from its ores by a process of distillation and condensation, and still is to a large extent. The first step is to convert the sulphide, carbonate, or silicate ores to the oxide by heating them. The sulphide is thereby converted into zinc oxide and sulphur dioxide, the latter, being a gas goes off, and in many cases is converted into sulphuric acid. The carbonate, when gently heated, is converted into zinc oxide and the oxides of carbon; also gases. The oxide is reduced to metal by heating strongly with carbon (coal). The roasted ore requires from 33 to 50% its weight of coal, the two being intimately mixed and charged into fireclay retorts or muffles, the average charge containing from 40 to 50% of coal and weighing about 60 lb. per retort. The latter are arranged in batteries in a furnace, so that a tubular extension (prolong) connected to the retort projected through the walls, for attachment to fireclay condensers. Upon heating the retorts the oxygen in the oxide combines with the carbon in the fuel, evolving carbon monoxide, which passes away with the zinc vapor, and the vapor is cooled in the condensers to liquid zinc. A portion of the zinc is also evolved as zinc dust, a mixture of zinc and zinc oxide, from which it is difficult to recover the metal, consequently every effort is directed towards keeping the percentage of zinc dust as low as possible, although there is always a fair market for this by-product to be used as a precipitant for gold and silver from cyanide solutions.

Electrolytic zinc.—The distillation process being considered unsatisfactory by many metallurgists, efforts were directed towards solving the problem of obtaining zinc electrolytically, and processes have been developed, so that a considerable amount of zinc is now obtained by this process.

Briefly, this includes roasting, leaching, electrolysing, and smelting. Roasting is necessary to convert the zinc and lead sulphides in the ore into sulphates, to oxidize the iron, and ex-

pel the sulphur as much as possible. A product suitable for dissolution in dilute sulphuric acids is produced. The roasted ore is dumped into a tank partly filled with the leaching solution, which is the acid electrolyte from the plating cells. Sufficient ore is added to consume the acid in the solution, then ground limestone is added to make sure of the neutralization of the acid, when the zinc-bearing solution is run off, purified, thickened, and clarified. It then flows into cells where it is

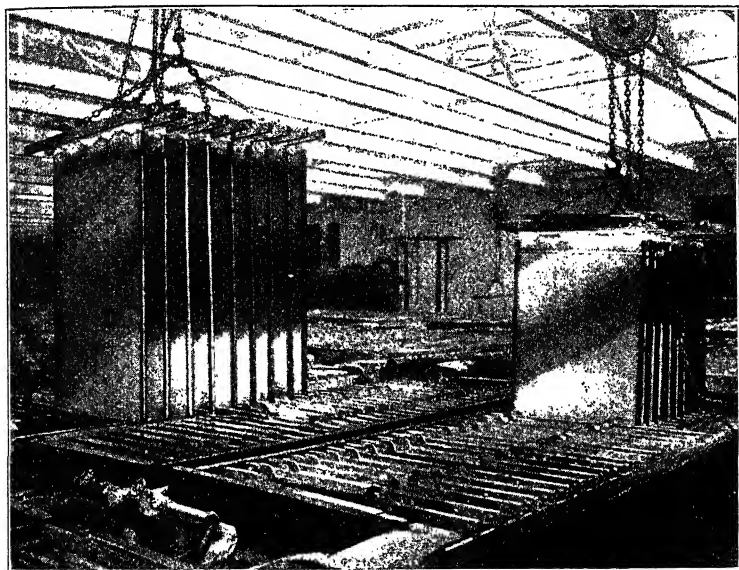


Figure 12.—Electrolytic zinc plant. Drawing zinc at Great Falls reduction department of Anaconda Copper Mining Co.

electrolysed, and the zinc is removed as metal by being plated onto aluminum sheets forming the cathodes from which it is stripped at intervals. Figure 12 shows cathodes being hoisted from the tanks—drawing zinc, it is termed—at the plant of the Anaconda company, at Great Falls, Montana. When run into the cells, the solution contains no free acid, but as the zinc is removed, acid is formed, and when the zinc is all plated out, the solution will contain about $1\frac{1}{2}$ times as much acid as there was zinc removed. This makes the leaching solution.

Casting zinc.—The stripped deposited zinc is now melted and run into ingots, using both coal-fired and electrically-heated furnaces. The molten zinc is cast into slabs by hand, from ladles carried by trolleys (figure 13). The electrolytic zinc produced at the zinc refinery of the Anaconda company has a certified zinc content of 99.90%, and is thus one of the purest of commercial metals.

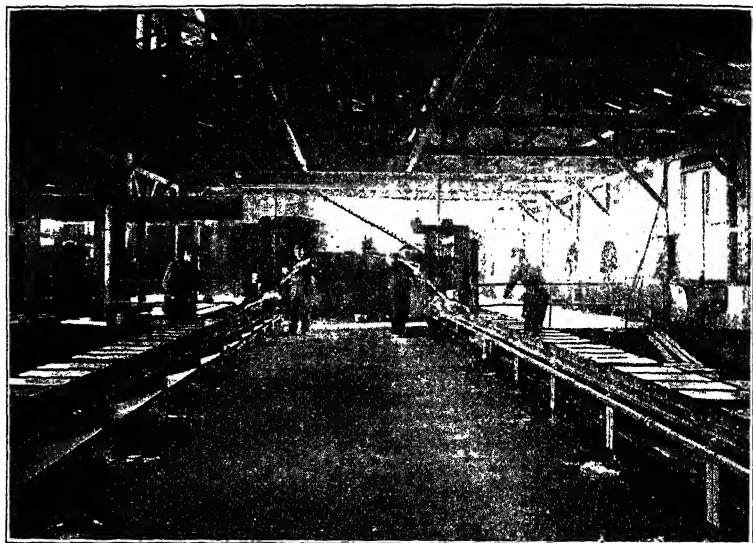


Figure 13.—Electrolytic zinc plant. Casting zinc at Great Falls reduction department of Anaconda Copper Mining Co.

The size of the electrolytic slab is $15\frac{1}{2}$ by 10 by $1\frac{1}{2}$ inches, and the weight is 50 lb. It is known as “Anaconda Electric” zinc.

BRANDS OF ZINC

The New Jersey Zinc Co. produces six brands of zinc, namely (1) Horse Head; (2) Bertha; (3) Sterling (4) Franklin; (5) White Bronze; and (6) Nassau.

Horse Head spelter.—This brand is the highest quality of zinc (spelter) the company makes, it averaging more than 99.94% pure. It is obtained from Franklin, New Jersey, ores.

The limit schedule of chemical impurities of this brand is given by the company as follows:

	Per cent
Lead.....	0.05
Iron.....	0.011
Cadmium.....	0.000

Bertha spelter.—This spelter is similar to Horse Head, as are its chemical impurities. Both brands are shipped in slabs, 18¾ inches long, 8¾ inches wide, and 1¼ inches thick, weighing 47 pounds.

Sterling spelter.—This brand is of a quality that will conform to the requirements of the U. S. Army Ordnance Department, for Grade A spelter. The limit schedule of chemical impurities follows:

	Per cent
Zinc (maximum)	99.50
Lead (maximum).....	0.10
Iron.....	0.03
Cadmium.....	0.50
Aluminum.....	0.00

Franklin spelter.—This zinc is produced from Franklin, New Jersey, ores, and contains no cadmium. The limit of chemical impurities allowed in this brand are,

	Per cent
Lead.....	0.3 to 0.5
Iron.....	0.0 to 0.015

White bronze.—This is a spelter with a restricted and uniform lead content, and contains,

	Per cent
Lead.....	0.12 to 0.20
Iron.....	0.00 to 0.015
Lead plus iron plus cadmium.....	0.12 to 0.25

Nassau spelter.—This brand is made in three grades as follows:

Brass special (3) grade.—This grade conforms to the requirements of the U. S. Army Signal Corps (Specification No. 11,012) for "Brass Special" or "C" spelter; and to the American Society for Testing Materials specifications for

"Brass Special" or "3" spelter. The limit schedule of chemical impurities follows:

	Per cent
Zinc (maximum).....	99.00
Lead (maximum).....	0.60
Iron.....	0.03
Cadmium.....	0.50
Aluminum.....	0.00
Lead plus iron plus cadmium (maximum).....	1.00

Selected (4) grade.—This grade will meet the specifications of the U. S. Army Signal Corps (Specification No. 11,012) for "Selected" or "D" spelter; also the A. S. T. M. specifications for "Selected" or "4" spelter. The impurities are as follows:

	Per cent
Zinc (maximum).....	98.75
Lead (maximum).....	0.80
Iron.....	0.04
Cadmium.....	0.75
Aluminum.....	0.00
Lead plus iron plus cadmium.....	1.25

Prime Western (5) grade.—This grade meets the requirements of the Army Signal Corps (Specification No. 11,012) for "Prime Western" or "E" spelter; also the A. S. T. M. specifications for "Prime Western" or "5" spelter. It contains:

	Per cent
Lead (maximum).....	1.60
Iron.....	0.08
Zinc (minimum).....	remainder

SPECIFICATIONS FOR SPELTER

The American Society for Testing Materials has adopted the following revised specifications for spelter:

1. *High grade.*—This spelter shall not contain over 0.07% lead, 0.03% iron, and 0.07% cadmium. It shall be free from aluminum. The sum of the lead, iron, and cadmium shall not exceed 0.10%.

2. *Intermediate.*—This spelter shall not contain over 0.20% lead, 0.03% iron, and 0.50% cadmium.

3. *Brass specials*.—This spelter shall not contain over 0.60% lead, 0.03% iron, and 0.50% cadmium. It shall be free from aluminum. The sum of the lead, iron, and cadmium shall not exceed 1%.

4. *Selected*.—This spelter shall not contain over 0.80% lead, 0.04% iron, and 0.75% cadmium. It shall be free from aluminum. The sum of the lead, iron, and cadmium shall not exceed 1.25%.

5. *Prime Western*.—This spelter shall not contain over 1.60% lead, and 0.08% iron.

SPECIFICATIONS FOR SCRAP ZINC

The specifications adopted for scrap zinc by the National Association of Waste Material Dealers follow:

Zinc.—This must consist of clean sheet and cast zinc, also cast batteries to be free of loose oxide and dross, sal-ammoniac cans and other foreign materials.

Physical properties of zinc.—The physical and mechanical properties of zinc according to various authorities are as follows:

Physical properties of zinc

Atomic weight.....	65.37
Principal valence.....	2
Specific gravity.....	7.14
Specific heat at 0° C.....	0.0935
Melting point, ° C. and ° F.....	419.4 and 786.9
Boiling point, ° C. and ° F.....	930 and 1706
Linear coefficient of expansion.....	0.00002918
Latent heat of fusion, calories.....	22.6
Latent heat of vaporization, calories.....	446
Heat in solid at melting point, calories.....	45.2
Heat in liquid at melting point, calories.....	67.8
Heat in vapor at boiling point, calories.....	605
Vapor tension at melting point.....	0.3 × 10 ² mm. Hg
Specific heat of gas per kilogram.....	0.077
Thermal conductivity at 0° C.....	0.2653 (silver, 1.00)

CADMIUM

This element occurs in nature in a few minerals, such as the sulphide, greenockite, which contains 77.7% cadmium. Compounds of the metal frequently occur associated with zinc ores. As cadmium is more volatile than zinc, it is mainly found in

the first portion of the zinc distilled over into the receivers. Cadmium was discovered by Strohmeyer in 1818.

Properties.—Cadmium is a silver-white crystalline metal like tin, and possesses the same property as tin of giving out a crackling sound—"cry"—when bent. It is quite soft, but a small amount of zinc makes it brittle. On account of its ductility it can be readily rolled or beaten into sheet and very thin foil, the latter being more coherent than tin foil, and having, similar to lead foil, a dull sound. On rolling, cadmium does not completely lose its crystalline structure. Its specific gravity is 8.6, it melts at 608° F., and boils at 1580° F. It is readily dissolved by mineral acids; but contact with platinum preserves it from the action of strong nitric acid.

Alloys of cadmium.—With gold, platinum, copper, and partly with mercury, cadmium yields brittle alloys; but with lead, tin, and in certain proportions with silver and mercury, very ductile combinations. For instance, 1 to 2 parts silver with 1 part cadmium is a ductile alloy, while 1 of 2 parts cadmium and 1 part silver is brittle. Equal parts of cadmium and mercury give a very plastic, malleable amalgam, while 1 part cadmium and 2 parts mercury is just as malleable but not so tough. According to de Souza, cadmium amalgam retains mercury at 680° F., but no longer at 824° F. Alloys of cadmium with bismuth and lead are readily fusible, and those of tin and cadmium very ductile. By combining cadmium with tin, bismuth, and lead, in certain proportions, alloys are formed, which, on account of their low fusing points, find many technical applications.

Cadmium in solders.—Cadmium is used in solders for aluminum, and in place of tin in ordinary solders. It has also been proposed for a bearing metal. The following alloy was patented by Hans Kreusler of Wilmersdorf, Germany:

	Per cent
Cadmium.....	45.00
Zinc.....	45.00
Antimony.....	10.00

Plating with cadmium.—Cadmium has also been used as

a covering for other metals, electrolytically deposited. It is claimed to be whiter than nickel, but less so than silver; while the deposit is harder than tin, and takes a good polish. One of the largest uses of cadmium is in the manufacture of sterling silver. It was stated by Erwin S. Sperry that the addition of 0.50% of cadmium to sterling silver imparts malleability to the alloy, and prevents, to a certain extent, the formation of blisters. Practically every manufacturer of sterling silver uses cadmium for rolling or for sand or plaster casting. Cadmium can be rolled into very thin sheets, as the metal is very malleable.

Cadmium in copper and bronze.—As a deoxidizing agent for the production of copper castings, cadmium is of about the same value as zinc, but it must be added in quantity. Alloys of copper and cadmium with as high as 50% cadmium have been made, but owing to the fact that the cadmium volatilizes so easily, they cannot be made by direct alloying. This rich alloy was used to add cadmium to copper or bronze, as metal containing this element is considered by some makers to be superior for trolley wire. Cadmium, so far, is not very important in making alloys useful in the brass foundry.

MERCURY OR QUICKSILVER

This remarkable metal has also been known from remote times, and, perhaps more than all others, has excited the attention and curiosity of experimenters by reason of its peculiar physical properties. Metallic mercury is occasionally found free, and in union with silver and gold, but its chief source is the sulphide or cinnabar (HgS). It is recovered from this ore by distillation and condensation. The ore is generally of low grade, much of it under 1% metal. Mercury has a nearly silver-white color and a very high degree of luster. It is liquid at ordinary temperatures, and solidifies only when cooled to -40°F . In this state it is soft and malleable. The specific gravity of pure mercury is 13.596. It boils at 662°F ., but volatilizes to a sensible extent at all

temperatures. In regard to its behavior in the air, it is a medium between the metals, readily combining with oxygen and those which show no special affinity for it. Since it does not combine with oxygen at an ordinary temperature, and retains its metallic luster even in a moist atmosphere, it has been included among the so-called "noble" metals.

When heated for some time to near its boiling point, mercury slowly absorbs oxygen and is gradually converted into a bright red crystalline powder—mercuric oxide. By heating the oxide thus formed somewhat more strongly, it is again decomposed into its constituents, oxygen and metallic mercury.

Amalgams.—Mercury alloys, or, as it is generally termed, "amalgamates" directly with many metals; but the real amalgam is with gold and silver. The process is coating, penetration, and dissolution, forming a plastic mass. Quicksilver does not amalgamate with platinum unless sodium is present. The amalgams in general are either liquid—the degree of fluidity depending on the quantity of metals compounded with the mercury—or they form solid bodies with perceptible crystallization and sometimes a high degree of hardness.

FAMILY 3, GROUP A

5. The metals of family 3, group A, are boron, aluminum, scandium, yttrium, lanthanum, and ytterbium.

BORON

Boron is never found in "native condition," but always in combination, usually with oxygen and sodium. While it is widely diffused, it is not often found concentrated in any one place. One of its best known compounds is borax, which occurs as immense bedded deposits of colemanite in California and Nevada. Some borax is recovered from brines of the Western States. Borax is a compound of boron, sodium, oxygen, and water, its chemical formula being $\text{Na}_2\text{B}_4\text{O}_7 \cdot -$

$10\text{H}_2\text{O}$. It is used as a flux in melting and brazing metals. Boric acid is another compound of boron. Its chemical formula $\text{B}(\text{OH})_3$, and it is also used in melting metals, being a good flux to use in melting some non-ferrous metals, but rather costly. At a red heat, boric acid parts with its water and becomes boric anhydride (B_2O_3), or fused boric acid. This is the form in which it should be used when melting metals.

When boric anhydride is heated with magnesium powder, the latter takes a portion of its oxygen leaving what has been termed a lower oxide of boron, the exact formula of which is not known. The magnesium changes to magnesia and is lost; the suboxide of boron, however, is not satisfied with the oxygen left to it, and is constantly seeking to combine with more and return to its former condition of boric anhydride. Consequently if it can be brought into intimate contact with the cuprous oxide in copper at a suitable temperature (the copper must be superheated), the suboxide will remove the oxygen from the copper and thus deoxidize it, and result in sound castings being obtained.

Boron nitride, a compound of boron and nitrogen, can be used in a similar manner. The element boron is very difficult to isolate; even aluminum will not reduce boric anhydride to boron, but forms therewith a compound of boron and aluminum, with probably some oxygen and nitrogen, which is not soluble in copper.

Aluminum can be rendered hard and brittle by "alloying" with this compound of boron, and this fact has led to the mistaken belief that the boron was alloyed with the aluminum. When such hardened aluminum is added to molten copper, however, an alloy of aluminum and copper only is formed, because the combined boron is not soluble in copper. The boron compound is thrown out and is merely skimmed from the metal, and no good effect is observable, because nothing has been added to the copper, except aluminum, and there is no improvement obtained in clean and sound castings of aluminum bronze.

As far as is now known, boron or its compounds is only

absorbed by those metals that take up carbon, and as copper is not one of these metals, it is not possible with our present knowledge to produce alloys of copper and boron; and although claims have from time to time been made to the contrary, analyses have not been at all favorable to such claims.

ALUMINUM

This element is a bluish-white metal when polished and air-oxidized. It was discovered by Wohler in 1828, who obtained it in small quantities by decomposing the chloride with potassium, in the same manner as magnesium was first obtained. The French chemist Deville was the first to prepare it on a commercial scale by the decomposition of a double chloride of aluminum and sodium, by metallic sodium. The success of this method excited much interest in all countries. A Philadelphia newspaper of the year 1856, under the caption "A New Metal Brought into Use" stated:

At a meeting of the Academie des Sciences, on the 6th day of February last, M. Dumas communicated the experiments of M. St. Claire Deville. This distinguished chemist, by a modification of M. Wohler's method, succeeded in obtaining aluminum in small bars and threads. The metal is as white as silver, does not tarnish, and is ductile in the highest degree. Its point of fusion is about the same as silver; its density 2.56. It is a good conductor and can be melted and cast in the air, without a sensible oxidation. Sulphuretted hydrogen, cold and hot water, nitric acid, heat, sulphuric acid do not act upon it; its true dissolvent is hydrochloric acid.

When M. Dumas had finished, Chevreul, Payen, Regnault, Le Verrier, and other distinguished members, gathered around the speaker to admire the plates of aluminum which were exposed in water, weak sulphuric acid, and nitric acid. M. Thenard moved, and it was carried unanimously, that the necessary funds be allowed for experiments upon a large scale. Should these experiments be successful, and this new metal—which has all the good qualities of silver, is as malleable as gold, and yet is lighter than glass, and which can be obtained from common clay—be brought into general use, it is easy to predict that silver would have had its day for the purposes of domestic life. Cooking utensils, plates and dishes, spoons and forks, drinking cups, will all be of aluminum. Should Deville's new experiments prove as successful as the old, he will have rendered mankind a signal service by his discovery.

A few months later we find in the same paper the following:

Your readers will remember what a lively interest was created a few months ago by the beautiful experiments made by M. St. Claire Deville, on the extraction of aluminum from clay. In the hope of giving to the arts and to commerce a metal so abundantly spread through the earth—to such a point that the most common clay contained 25% of its weight, and whose properties rendered it so precious—the Academy of Sciences of Paris made a donation of funds to M. Deville to carry his experiments further. Thanks to the liberality of the Academy, the most extensive experiments have been made, and with the most gratifying results.

Large medals have been struck in this metal, and these, no more than the small strips shown to the Academy at its last sitting, undergo any alteration in contact with the air. Small pieces, handled every day for months, have not lost their brilliancy. It is so inoxidizable, that it resists the action of air in a muffle heated to a temperature equal to that required for the assay of gold. Lead burns in the test and vitrifies at the side of the aluminum, without the latter losing any of its properties. The metal conducts electricity eight times better than iron; as well, and perhaps better than silver. It does not alloy itself with mercury, and takes but few traces from lead. It gives with copper, slight traces, very hard and very black, even when the copper amounts to 25% of the composition of the mélange. It is characterized at the highest point by the faculty of forming with charcoal, and especially with silicium, a gray casting, porous and brittle, crystallizing with the greatest facility. When the casting is attacked with hydrochloric acid the sulphuretted hydrogen which is disengaged, indicates the presence of the charcoal; but that which it contains especially is silicium, which separates in a state of purity when they have prolonged the action of the chlorohydric acid, concentrated, and boiling. The silicium exists in brilliant metallic strips like the filings of platina. The author thinks that this new form of silicium, is to the ordinary silicium what plumbago is to charcoal.

This body possesses with an inalterability more complete, all the chemical properties which Berzelius attributes to the residue of the imperfect combustion of ordinary silicium. To give an idea of this indifference to the action of the most energetic reactivities, M. Deville placed under the eyes of the Academy a fragment of the new silicium, which having been heated to a white heat in a current of pure oxygen, did not change its weight. This silicium conducts electricity like pure plumbago. The casting of aluminum from which it was extracted contained less than 10%. In terminating his discourse, M. Deville described two modes for the preparation of aluminum, the one by silicium, the other by the pile.

From the above accounts we note that great hopes were entertained as to the future of aluminum, also that the metal made by Deville contained considerable silicon, over 10% in some cases; which is interesting, in view of the fact that aluminum-silicon alloys are regarded as being a modern innovation. Deville's reference to the "pile" may be taken as meaning that he was familiar with a process of producing aluminum electrolytically, the modern process responsible for cheap aluminum. The aluminum of Deville was supposed to have been all made by the sodium reduction process, and some idea of its cost may be gathered from the remarks of Professor Seely at a meeting of the Lyceum of Natural History in Philadelphia in 1867. Dealing with the manufacture of metallic sodium, he stated that works had just been erected in the city (Philadelphia) for the production of tons of a metal which a few years since was sold by the grain. Instead of taking the wrought-iron mercury bottle formerly employed for the production of sodium, they now employed retorts made of boiler iron, 4 feet in length and 5 inches in diameter. These were protected by a case of plumbago or fireclay, as they were subjected to a white heat. The actual cost of sodium in the United States he said, need not exceed \$4 a pound. As it is lighter than water, a pound will go a long way. In England the theoretical cost was then 75 cents a pound. Sodium was at that time extensively employed in the amalgamation of gold according to the Wurtz process, also in the manufacture of magnesium and aluminum.

With sodium at \$4 a pound, aluminum made by this process would cost about as many dollars per pound as it now costs cents, or a hundred times as much as now.

MANUFACTURE OF ALUMINUM

The modern process of producing aluminum by electrolysis came into use in about 1887, being developed in France by Heroult, and by Bradley and Hall in the United States. In figure 14 is shown the furnace devised by Heroult.

Raw materials.—The raw materials for making aluminum are alumina, cryolite, and the electrodes for the furnace, which are used up and play a part in the reduction of the alumina. The alumina is obtained from bauxite, a hydroxide of aluminum in combination with a hydroxide of iron. As the

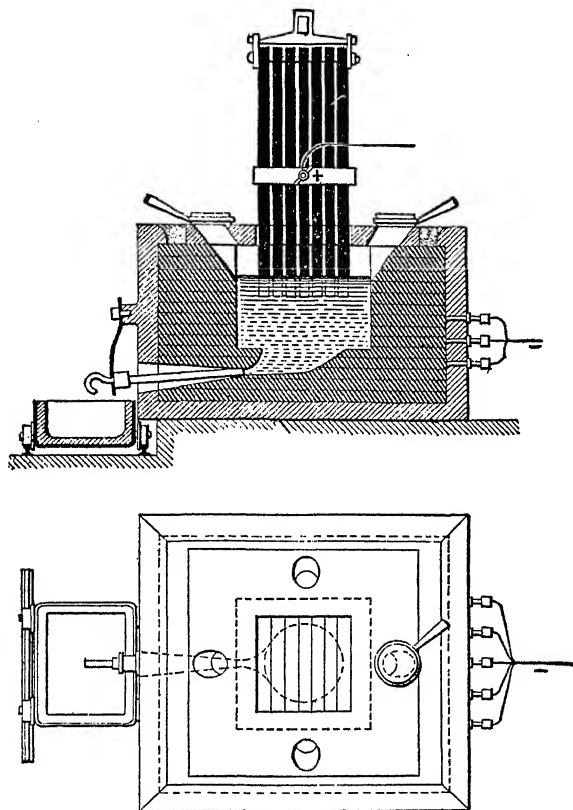


Figure 14.—Aluminum furnace used by Heroult.

metal aluminum cannot be purified by the melting and oxidizing operations as used in the reduction of copper, the only way to get it in a state of purity is to use pure materials in making it. The bauxite as mined contains from 50 to 75% alumina and 1 to 30% of iron and silica; so if the ore were used in the raw state, these metals would pass into the aluminum, and could not be separated therefrom.

Purification of bauxite.—The bauxite has to be purified, or rather the pure oxide of alumina has to be obtained from it, and two methods are in use to accomplish this end. These methods are the Le Chatelier and Morin, and the von Bayer method. The first is the older method, and consists in roasting the powdered bauxite with sodium carbonate in the proportions of 75% bauxite and 25% soda. This mixture is heated to bright redness in a magnesite-lined reverberatory furnace, whereby sodium aluminate is formed together with silica and iron oxide. This is leached with warm water which separates the aluminate by dissolving it. The impurities carried by the solution are separated by filtration, and the filtrate is treated with carbon dioxide gas, which being passed through it, precipitates the alumina as hydrate. The process takes 5 to 6 hours at 70° C. The precipitated alumina has to be washed, filtered, and dried, and then calcined to alumina in a revolving furnace. It is then in shape to be used for the production of aluminum. In the Bayer process, the bauxite is put into an autoclave, which is a boiler-plate vessel about 4 feet diameter and 10 feet long, holding about 3 tons of solution at a charge. The bauxite is crushed to pea size, calcined or roasted, ground very fine, added to a caustic soda solution of 1.45 specific gravity, and the mixture heated in the autoclave with steam at 5 to 6 atmospheres (1 atmosphere = 15 lb. per sq. in.), pressure for 3 or 4 hours at a temperature of 150 to 160° C. By this treatment about 96% of the bauxite content is extracted as sodium aluminate, when the solution is passed into another vessel, being filtered on its flow thereto. The filtered solution is diluted to a specific gravity of 1.23, and is agitated by a mechanical stirring device in autoclaves as shown in figure 15, a small quantity of freshly precipitated hydrate of alumina being added. This precipitates about 70% of the dissolved alumina, which is separated by filtration and then filter-pressed under a pressure of 5 atmospheres to cakes which are air-dried in magnesium-lined tubular kilns. The water is driven out by this treatment, but to render the alumina less hygroscopic, it is heated to a red

heat, about 1100°C . The diluted soda solution is evaporated to a specific gravity of 1.45 in vacuum stills, and can be used over again.

Both of the above processes of obtaining alumina have to be operated on a bauxite with low silica content, and for this

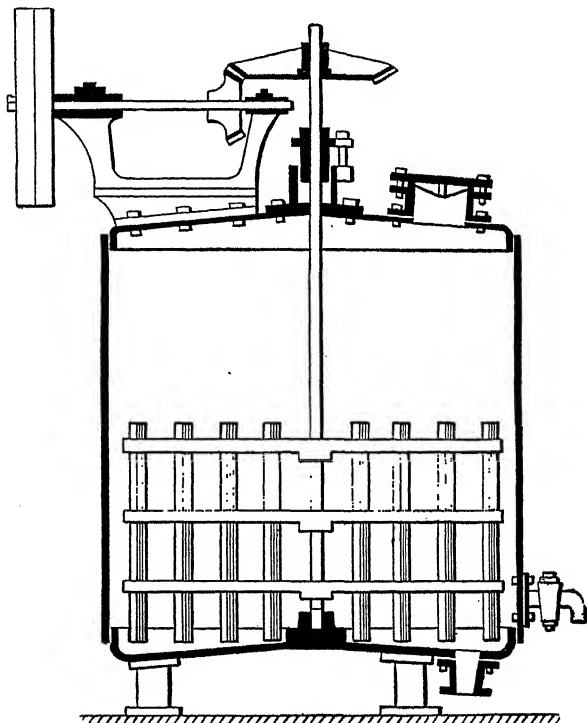


Figure 15.—Autoclave used in purifying bauxite.

reason a high silica clay cannot be used, as the silica causes a loss of alumina in the soda solution.

The natural cryolite in which the alumina is dissolved is found at Tvigtut, Greenland, and at Miask in the Urals. It is selected by hand-sorting as it is mixed with quartz, iron, and lead; and is further dressed by passing over electromagnets. Cryolite is also made artificially. The mineral melts at about 1000°C ., but its melting point is lowered by the addition of alumina; the addition of aluminum fluoride, an-

other constituent of the bath, also further lowers its melting point.

In figure 16 is shown one of the more modern aluminum producing furnaces of European design. The charge of the furnace consists of cryolite, aluminum fluoride, and chlorides of aluminum, potassium and sodium. About 20% of aluminum oxide is added, which dissolves in the molten salts, and

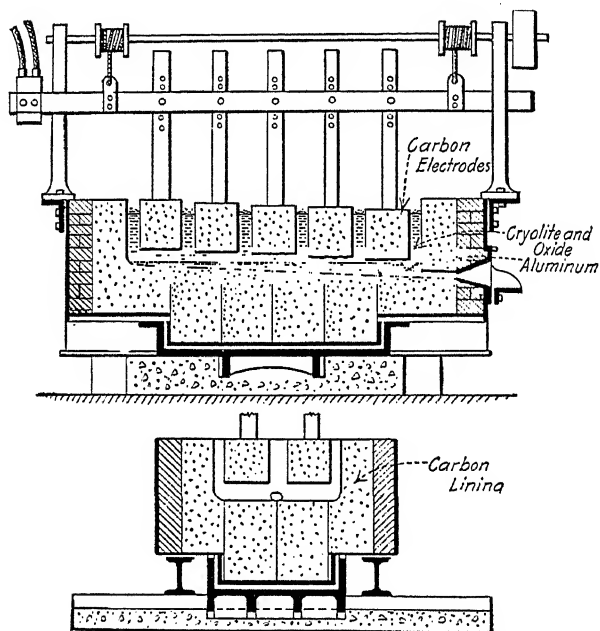


Figure 16.—An aluminum-making furnace of European design.

the aluminum is separated by a direct electric current, and sinks to the bottom of the bath. From there it is tapped every 24 hours into small ladles, which are emptied into a large mixing ladle, from which it is poured into ingot molds, thus producing commercial aluminum.

The body of the furnace is rectangular in form, as shown, and is about 3 by 3 by 6 feet. It is simply a box lined with carbon, which serves as the cathode, while the anodes are

carbon conductors suspended from copper bars in any convenient manner. These conductors may be either square or round, and the electrolysis is carried out at a temperature ranging from 1650 to 1850° F., using a current density of about 700 amperes per square foot, and an electrode potential of 7.5 to 8.5 volts. (U. S. Bureau of Standards Circular No. 76, page 5.)

The heating is accomplished by this current in the case of the large equipment commercially used; but on a small scale, as in experimental work, the heat evolved by the passage of the current would not be sufficient to keep the bath in a state of fusion, and it would be necessary to use external means of heating to supplement that of the electric current.

As the operation proceeds, the carbon anodes are attacked by the oxygen liberated from the alumina, therefore the lining and the anodes are rapidly worn away, and the anodes must be lowered into the bath occasionally. The amount of carbon consumed from anodes and lining practically equals the weight of aluminum produced, and this is one of the fixed factors that enters into the cost of producing aluminum by electrolysis. A current of one ampere flowing through the bath for one hour would produce 0.000743 lb. of aluminum, therefore, a current of 10,000 amperes flowing for 24 hours would produce 179 lb., provided an efficiency of 100% was realized. In practice, however, an efficiency of only 75% is obtained, so that a current of 10,000 amperes flowing for 24 hours produces only a little over 134 lb. of aluminum.

The production of cheap aluminum is dependent upon low-cost methods of refining the ore, and on cheap electric power. On account of this latter factor production of aluminum is dependent upon the utilization of water-power, and is in the hands of a comparatively few large firms.

Grades of aluminum.—Two commercial grades of metal are produced in the United States, namely, grade A, containing 99% or more aluminum, and grade B, containing from 98 to 99% aluminum. The first grade is largely used for wrought aluminum ware, and in the preparation of light

alloys for rolling and castings. The second grade is used in the steel industry, and sometimes for casting alloys.

The chief impurities in commercial aluminum are iron and silicon, with traces of copper and sodium. Considering the natural impurities contained in the ores from which it is produced, and the impossibility of refining the metal after it is once made, commercial aluminum is remarkable for its purity. The average of four samples of purest commercial aluminum as given in Bureau of Standards Circular No. 76, is as follows:

Average analysis of four samples of commercial aluminum

Elements	Per cent
Aluminum.....	99.2606
Copper.....	0.0382
Iron.....	0.2350
Zinc.....	0.0072
Silicon.....	0.0580
Silica.....	0.3560
Nitrogen.....	0.0450
	<hr/>
	100.0000

Grade A aluminum will normally average 99.3% metal, with silicon varying from 0.15 to 0.40%, and iron from 0.25 to 0.70%. The iron usually exceeds the silicon, but neither of these impurities is present in amount sufficient to be harmful. For casting purposes, the effect of silicon is to modify the shrinkage of aluminum alloys, and it is now being added with that view up to 14%. On the other hand, for making aluminum bronze, silicon is injurious, and its limit in aluminum used for this purpose may be put at 0.5%. Iron is not harmful in aluminum bronze, as it is deliberately added up to 12% of the bronze. In alloys with a base of aluminum, iron is frequently found in amount up to 1% and over. These two impurities, therefore, may be regarded as not especially harmful in aluminum.

Aluminum is only superficially oxidized by damp or dry air, and in massive form is only slightly affected by water. It is rapidly attacked by sodium and potassium hydroxides (NaOH and KOH), also by hydrochloric acid and mercuric

salts. When finely divided it is attacked by nitric acid at 100° F., and the hotter the solution the more rapid the action; but in massive form it resists this acid to a remarkable degree, when it is considered how other non-ferrous metals are attacked by this acid. Dilute and concentrated sulphuric acid attack aluminum slowly when cold, but dissolve it when heated with the production of sulphur dioxide. The action of these acids is greatly modified by the purity of the metal, and also by its mechanical condition; hammered aluminum being least attacked, rolled metal next, and then the drawn metal, while cast aluminum is more easily attacked than the other forms.

Chlorine, bromine, iodine, and fluorine attack aluminum and corrode it. It is not affected by sulphuretted hydrogen or other sulphurous vapors. Aluminum is a widely distributed metal, but many of its combinations are too impure to be utilized by present methods. It is never found in the metallic state, but always combined with oxygen in the form of clay, feldspar, and other double and complex silicates. Corundum, sapphire, and ruby consist mostly of alumina, generally over 90%, with silica and 1% of iron. The hardness of corundum is 9, being next in order to the diamond.

Uses of aluminum.—These are very numerous, not only for strictly alloying purposes and as a metal, but it is rolled and beaten into foil which can be used in place of tin, in a comminuted form it is used as a paint, also as an explosive in warfare only, and in the manufacture of fireworks. In granular form it is used as a reduction material, also when mixed in proper proportion with iron oxide it forms the well-known thermit, used extensively for welding together the broken parts of machinery, steel rails, etc. In fact, aluminum is fast becoming a most important metal, and there is reason to believe that as new methods of obtaining it from its compounds are discovered its production cost will be still further lowered.

The latest use of aluminum is in castings for statues. Late in 1922, G. Morretti, a sculptor of Pittsburgh, Pa., executed a life-size figure of Charles Martin Hall—the inventor of the

electrolytic process of making aluminum—which was cast by the Aluminum Company of America, and is now on view in the Carnegie Institute of Pittsburgh. This is the first statue ever cast in aluminum, and is of high artistic quality and beauty. Several statuettes have also been cast, showing fine lines. A thin, practically invisible patina, which prevents corrosion, forms on it in damp air. Its use opens a wide field in the world of art.

The physical properties of this metal according to various authorities, are tabulated as follows:

Physical properties of aluminum

Atomic weight.....	27.1
Principal valence.....	3
Specific gravity.....	2.7
Melting point, °C. and °F. (Bureau of Standards) ..	658.68 and 1218
Boiling point, °C. and °F. (Greenwood).....	1800 and 3272
Specific heat, from 18 to 100° C. (Jaeger and Dieselhorst).....	0.2124 plus 0.000104t
Linear coefficient of expansion.....	0.0000245
Electrical conductivity (International Standard by volume).....	60.86
Electrical conductivity for Foundry figures, taking copper as 98%.....	61
Ultimate tensile strength, lb. per sq. in.....	12,900
Yield point, lb. per sq. in.....	4,700
Elongation, % in 2 inches.....	29
Reduction of area on cast specimens, %.....	38.5

The foregoing tensile, yield point, elongation, and reduction were obtained on test bars, cast-to-size in sand molds using re-melted commercially pure aluminum.

SCANDIUM

This element, and the three remaining ones of its group (yttrium, lanthanum, and ytterbium), need not be considered in a work of this character.

FAMILY 3, GROUP B

6. The elements in family 3, group B, are gallium, indium, and thallium.

GALLIUM

This element was discovered in 1875 by Lecoq de Boisbaudran, and from patriotic motives he named it gallium, after his native land. It is usually found associated with zinc minerals, but nowhere in very large quantities. It is a peculiar metal owing to its low melting point (about 87° F.); it will melt when held in the hand, and in some climates would exist as a liquid. It is a soft metal, easily cut with a knife, and would no doubt be very useful in certain alloys if it could be procured in quantity. It is soluble in hydrochloric acid and warm nitric acid, and is attacked slightly by the caustic alkalis.

INDIUM

This rare metal, discovered in 1863 by Reich and Richter in the zinc blende of Freiberg, is also found in very small quantities in a few other zinc ores, and when these are worked for zinc, the indium alloys itself with the zinc. Indium is a white lustrous metal with a specific gravity of 7.4, and melts at 349° F. It remains unchanged in the air, but burns with a violet light when heated to redness, and produces brown vapors. It dissolves slowly in hydrochloric acid or dilute sulphuric acid, but easily in nitric acid.

THALLIUM

This element was discovered at the same time as the elements caesium and rubidium, and in the same manner, namely, by the spectroscope, where it showed as a bright green line, and was appropriately named thallium, from *thallus*, the Latin for a budding twig. Its discoverer was Crookes. The chief source of thallium is the flue-dust from acid works and smelters operating upon copper and iron pyrite and zinc ores. The metal resembles lead; it is soft and malleable, and melts easily at about 570° F. It forms alloys with many metals, but does not appear to have much commercial application.

FAMILY 4, GROUP A

7. In family 4, group A, are included carbon, silicon, titanium, zirconium, cerium, and thorium.

CARBON

Carbon is the most widely diffused element, and few elements are capable of assuming so many different forms, crystalline or amorphous. For instance, it is transparent and colorless as in the diamond, opaque and black in graphite or plumbago, velvety and porous in wood charcoal, also in coal, coke, and carbon black. For our purpose only the forms known as graphite and coal are of interest.

Carbon, for which no actual solvent is known, has the remarkable property of dissolving in considerable quantities in several molten metals, the best known example of this being its behavior towards iron. As is well known, in the manufacture of iron, the pure metal is never obtained, but cast iron, which contains a certain quantity of carbon, is. There can be no doubt that the carbon is actually dissolved in the iron, as when certain varieties of cast iron containing much carbon are cooled, some carbon is separated out in a crystalline form as graphite.

This carbon, as previously stated in speaking of iron, exerts a considerable influence upon the qualities of a metal, the special properties of the various kinds of iron known as cast iron, wrought iron and steel, being chiefly due to the varying quantity of carbon they contain.

SILICON

This element was discovered by Berzelius in 1823. It is never found isolated in nature, even though it is very inert at ordinary temperatures. It always exists in combination with other elements, and most of these combinations are very useful industrially. Combined with oxygen it forms silica (SiO_2), one of the most common substances in the earth, and

one of the most useful. Rock crystal, quartz, opal, jasper, chalcedony, and flint are largely composed of silica. Most rock material consists of silica or a mixture of silicates.

Molding sands and core sands are largely silica, and the following table (No. 4) gives some typical analyses of such:

TABLE 4.—*Analyses of molding sands*

Constituents	Suitable for			
	Light iron work, %	Medium iron work, %	Heavy iron work, %	Light brass work, %
Silica.....	82.21	85.85	88.40	78.86
Alumina.....	9.48	8.27	6.30	7.89
Iron oxide.....	4.25	2.32	2.00	5.45
Calcium oxide.....	.....	0.50	0.78	0.50
Calcium carbonate..	0.68	0.29	.....	1.46
Magnesia.....	0.32	0.81	0.50	1.18
Soda.....	0.09	0.10	.....	0.13
Potash.....	0.05	0.03	.....	0.08
Manganese oxide...	.....	.....	0.25	.....
Combined water....	2.64	1.68	1.75	3.80
Organic matter.....	0.28	0.15	0.04	0.64
Specific gravity....	2.652	2.645	2.630	2.640

Fireclay is half silica, ganister contains 96 to 99%, and silica brick 88 to 95%, while all other bricks contain a large percentage of this element.

Carborundum is an artificial abrasive, and is made by passing an electric current through a mixture of sawdust, sand, and coke in a long, rectangular resistance furnace. The central core of the furnace is intensely heated by the passage of the current, the temperature reaching 2200° C. (3992° F.). The silicon is volatilized, and one molecule combines with one molecule of carbon to form carbide of silicon, and a core of pure crystalline carborundum forms in the furnace. Immediately surrounding this core is a layer of imperfectly formed carborundum, known as carborundum firesand, with which every brass foundryman is perfectly familiar.

Silicon itself is produced in a manner similar to carborundum: A mixture of coke and pure silica is melted in a large and special electric furnace. The product will contain from 90

to 96% silicon. An analysis of an exceptionally pure silicon, made by the U. S. Ferro Alloys Corporation, shows its product to contain 1.34% iron, 1.75% aluminum, 0.40% calcium, 0.40% magnesium, and 96.00 silicon.

Silicon in alloys.—Silicon is alloyed with both iron and copper. With cast iron it forms alloys noted for their resistance to the corrosive action of acids, and are used for castings used in the manufacture of acids and other apparatus. Rich alloys of iron and silicon are also made, and are used to carry silicon additions into iron and steel, for deoxidizing purposes, and to confer special properties on the iron. Alloys of silicon, manganese, and iron are also used in the steel industry. In non-ferrous metallurgy, silicon also plays an important part—for instance, with aluminum it makes a superior alloy for die-casting purposes. In alloy with copper it is used to deoxidize copper for castings, also under the name of silicon bronze it is largely used for telegraph wire. Silicon alloys to any extent with copper, it being merely a question of temperature: a 50-50 alloy of silicon and copper is black, hard, and brittle. Silicon is the greatest hardener of copper known; an alloy of copper and 10% silicon is so hard as to be as brittle as glass. When properly alloyed with copper, silicon produces an alloy resembling aluminum bronze in appearance and physical properties, but easy to handle in the foundry, as it is free of the high shrinkage and drossy troubles which attend the casting of aluminum bronze.

Perhaps the latest use for silicon is as an insoluble anode of ferro-silicon, developed by the Chile Copper Co. after six years of experimentation, and by the end of 1922 this anode had replaced other types at its electrolytic plant, which has a capacity of 220,000,000 lb. of copper per annum. This anode has reduced the cost of producing copper by $\frac{3}{4}$ cent per pound.

Silicon is sold in the form of flakes, dark violet in color and of a metallic luster. Silicon and its combinations have become so important in our industrial life that they may be regarded as indispensable.

Physical properties of silicon

Atomic weight.....	28.1
Principal valence.....	4
Specific gravity.....	2.49
Melting point, °C. and °F.....	1435 and 2615
Boiling point, °C. and °F.....	3500 and 6332
Specific heat at 0 °C.....	0.1697
Atomic volume.....	11.4
Linear coefficient of expansion.....	0.00000763

TITANIUM

This element was discovered in 1791 by McGregor, who gave it the name of "menachite," and it was re-discovered in 1794 by Klaproth, who gave it the name "titanium," in allusion to the Titans, the fabled giants of mythology. This latter name has been universally accepted. There are 60 distinct species of titanium-bearing minerals, chiefly oxides, titanates, titano-silicates, columbiates, silicates, and tantalates. Titanium is a relatively abundant element, as it stands in the ninth place in the scale of abundance. It occurs in largest quantity as the oxide (rutile), iron titanate (ilmenite), and iron ferrate (magnetite); also as titaniferous iron ore. Titanium-bearing ores may be found in granite, gneiss, mica-schist, and granular limestone.

Uses of titanium.—Titanium is used for deoxidizing and purifying steel, in the form of ferro-titanium and ferro-carbon-titanium. In non-ferrous metals it is used as manganese-titanium, and in alloy with copper, as titanium-copper. Its salts are used in arc-lamp electrodes, as mordants and dyes for leather and textiles, as a refractory coloring material for use in ceramics and artificial teeth; while its oxide mixed with barium and other sulphates, is used as a pigment.

Manufacture of titanium.—The metal itself is very difficult to obtain, on account of its strong affinity for oxygen, nitrogen, and carbon. Many methods of obtaining the element have been tried, but it is doubtful if any were successful except reduction of the tetrachloride by sodium; the same method as was resorted to for winning magnesium and aluminum. The reduction of titanium is more difficult than

either that of aluminum or magnesium, as its tetrachloride is a liquid, instead of a solid. The method devised by Hunter in 1912 was to enclose the tetrachloride in a bomb with sodium, and heat the bomb until a reaction occurred and the chlorine interchanged. As the reaction produces enormous pressure, a steel bomb must be used, in shape like the breech of a large gun, with thick walls and bottomed. The sodium is first placed in the bomb, then the cover of the vessel is screwed on, which requires several minutes. In the cover is a hole an inch or so in diameter, through which the tetrachloride is poured, and then closed by a threaded plug. After the reaction, the bomb is opened and the titanium is found as a scale lining the inside of the bomb. The titanium looks like pieces of steel. It is so hard that it will indelibly mark glass, leaving a silvery mark. While its melting point is supposed to be very high, the metal dissolves in copper with ease at a little above the melting point of the latter.

Titanium copper.—To make a pure copper-titanium, the copper is melted in a long crucible, the molten copper not filling the crucible more than one-third. The correct amount of titanium must be enclosed in a copper cup, which is dropped into the molten copper, and is speared with a carbon stirrer, and held submerged under the copper. The temperature of the copper is lowered by the comparatively large copper cup, but nevertheless the titanium will dissolve and alloy with the copper. In doing this, however, the copper will foam and rise in the crucible, so that if a small crucible were used, a large portion of the charge would be lost. After the titanium has alloyed with the copper, although it may be superheated, it is impossible to pour out the alloy owing to its viscosity; so the crucible must be withdrawn from the furnace, and a circular piece of steel shafting inserted centrally in the metal, which is allowed to congeal around this shaft. When cold, the titanium-copper is broken away, and being in the shape of part of a ring is easily divided into small pieces for adding to metals as a deoxidizer. A 10% titanium-copper (pure) is hard, and purplish-black on the surface, but when filed is

white, and rapidly tarnishes to a dirty red. When made as above it will contain approximately 7.46% of titanium. Apparently, it possesses little value for use in non-ferrous metals.

Ferro-carbon-titanium is used in large quantities in steel manufacture, from 300,000 to 1,000,000 lb. a month having been sold for years. Its average analysis is given by the

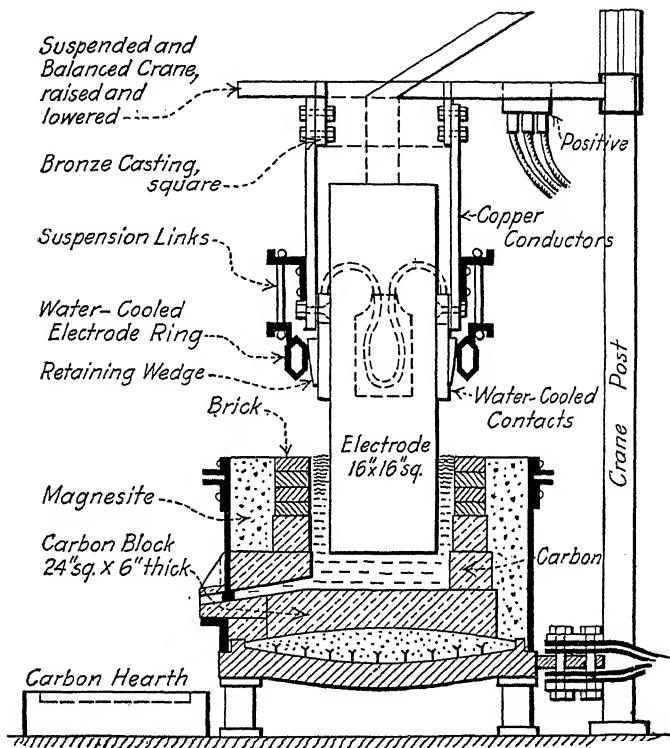


Figure 17.—Ferro-titanium furnace.

Titanium Alloy Mfg. Co. as follows: Titanium, 15.79%; silicon, 1.41%; carbon, 7.46%; manganese, 0.11%; aluminum, 0.80%; phosphorus, 0.05%; sulphur, 0.08%; and iron (by difference) 74.30%. A carbon-free ferro-titanium is also used in steel making; its analysis is given by the Metal and Thermit Corporation as follows: Titanium, 25.50%; carbon, none; manganese, 0.60%; aluminum, 5.75%; silicon, 0.35%; and

iron, 67.80%. Figure 17 gives details of a furnace for making ferro-titanium.

The ferro-carbon-titanium alloy is made in the electric furnace, and the carbon-free alloy is made by reduction with aluminum. Thus the one alloy contains an excess of carbon and the other an excess of aluminum. A considerable divergence of opinion exists as to the respective merits of these two titanium alloys.

Physical properties of titanium

Atomic weight.....	48.1
Principal valence.....	3 or 4
Specific gravity.....	4.5
Melting point, ° C. and ° F.....	1800 and 3272
Atomic volume.....	10.7
Specific heat at ° C.....	0.1125

ZIRCONIUM

This element is always found in the combined form, usually associated with oxygen. In recent years an abundant source of supply has been found in the mineral baddeleyite, consisting of from 88 to 98% zirconia, the average being about 84%. An average sample of baddeleyite will contain the following:

Analysis of baddeleyite

	Per cent
Zirconium oxide.....	84.10
Silicon oxide.....	7.75
Ferric oxide.....	3.10
Titanic oxide.....	1.21
Alumina.....	0.68
Ignition loss.....	2.80

Zirconium minerals.—The oxide of zirconium is known as zirconia, and it was isolated as a new earth by Klaproth in 1789. Berzelius examined the compound in 1818, and pointed out its resemblance to alumina, giving it the formula Zr_2O_3 . It was found later, however that the correct formula was ZrO_2 . The chief deposits of zirconia are in the State of Minas Geraes, Brazil, but there is considerable mineral in the Carolinas. Zirconium-bearing minerals are distinguished by their infusibility, high resistance to acid and basic slags, low

thermal conductivity, and low coefficient of expansion. These properties make them eminently suitable for use as refractories and as a consequence they are extensively used for this purpose. Zirconia is more refractory than silica; it serves a similar purpose with improved results, but is much more expensive owing to its comparative scarcity.

Metallic zirconium.—This metal is similar to titanium in the difficulty of preparing it. The first steps are to obtain the pure zirconium oxide; a somewhat tedious process. J. W. Marden and M. N. Rich of the U. S. Bureau of Mines, at Golden, Colorado, obtained the metal by aluminothermic reduction, using as the charge, 56.25% zirconium oxide, 18.75% potassium chlorate, and 25.00% aluminum.

The materials were all first thoroughly purified, then well mixed, and finally reduced in a fireclay crucible. The result was a coherent metal in small beads, with the following composition:

Analysis of zirconium metal

	Per cent
Zirconium.....	99.40 to 99.50
Titanium.....	0.45 to 0.40
Iron.....	0.01 to 0.02
Aluminum and silicon by difference...	0.14 to 0.08

It was found by these investigators that the zirconium—which was of a high degree of purity—made by the above process would not dissolve in lead, tin, or silver, by simply heating above the melting point of the respective metal. It would alloy with silver, aluminum, and iron, when heated above the melting point of zirconium in an Arsem furnace. Alloys of silver, iron, nickel, or aluminum were easily made by simultaneous reductions at high temperature, using the aluminothermic process. Zirconium does not form amalgams. Some of its properties are given by Marden and Rich as follows:

PROPERTIES OF ZIRCONIUM

Color.—White, metallic. Corrosion, does not rust or tarnish on long standing in the laboratory, but when polished remains bright; white like polished nickel.

Electrical conductivity.—Fairly good conductor, probably less than that of iron.

Fusibility.—Can be readily fused, under proper conditions, away from air, at about 1600°C .

Hardness.—About 6 to 7 on the Mohs scale. The hardness varies with the method of preparation and the purity of the sample. The pure samples were less hard than the impure metal. In all cases the metal would readily scratch glass. As would be expected with a metal of this degree of hardness, it was quite brittle, and could be easily broken by pounding lightly with a small hammer. The metal is still very hard, though less brittle, at a red heat. The hardness on the Shore scleroscope is 40 to 45.

Melting point.—About 1600°C . (2912°F). The U. S. Bureau of Standards has found the melting point of the metal to be from 1400 to 2200°C ., as it was prepared by various investigators. In recent trials the metal appeared to melt very close to 1600°C . in an atmosphere of pure, dry hydrogen.

According to Waldemar T. Schaller, in *Mineral Foote-Notes* for March 1918, metallic zirconium has not so far found any practical uses, though ferro-zirconium is used to some extent in the steel industry. One zirconium steel is said to be particularly suited for armor-plate, armor-piercing projectiles, and bullet-proof metal. An alloy of 65% zirconium, 26% iron, 7.7% aluminum, and 0.12% titanium is said to be highly resistant to chemicals, malleable, and makes good filaments for incandescent lamps, although this is very doubtful.

Cooperite is a patented alloy of zirconium and nickel for which many claims are made.

Zirconium in copper alloys.—Zirconium has not been used to any great extent in non-ferrous metallurgy. A few tests made by the author showed that this metal was free from the difficulty characteristic of titanium. The latter element renders copper alloys sluggish; the alloy separates into two portions, about 70% can be poured from the melting crucible, while 30% and over, depending on the titanium content, will be a pasty mass, possessed of no fluidity. This will happen

in the case of a 10% aluminum bronze containing 0.5% of titanium. Zirconium appears to be free of this undesirable property. The bronze containing zirconium could be poured freely, leaving no residue in the crucible. This is an important point in favor of zirconium, in case it is found to impart desirable properties to non-ferrous alloys.

For further and complete details of investigations into zirconium the reader is referred to U. S. Bureau of Mines Bulletin 186, 1921, 152 pages; also to "Zirconium and its Compounds," by F. P. Venable, one of the Monograph Series of the American Chemical Society, published in 1922.

CERIUM

This element belongs to what is known as the rare-earth group of metals, which comprises at the present time 18 elements, including thorium and zirconium, all bearing a great resemblance to each other, thus making it difficult to separate and purify them. They do not exist as free metals, but as compounds of the metals with oxygen and chlorine.

The chief source of these metals is monazite sand, the workable deposits of which exist in Brazil, India, and the Carolinas. The Brazilian deposits are the most important as they contain a greater percentage of thorium, the element that first gave value to these sands; also, the sands there are more even in quality and easier to work, as they are found on the sea shore.

Monazite sand is a mixture of the phosphates of the rare-earth metals, and contains from 25 to 35% of cerium oxide, and 5 to 7% thorium oxide, the remainder being oxides of the other rare-earth metals, with phosphoric acid and silica. For a long time this sand was worked for the thorium it contained, and after this was extracted the residue was discarded. The thorium was used in making incandescent gas mantles, by impregnating a woven fabric of the proper shape with a "lighting fluid" as it is technically termed, which deposits in the fibers of the cloth the oxides of thorium and cerium in

the proportions of 99 to 1. The lighting fluid consists of the nitrates of thorium and cerium with a small percentage of beryllium nitrate, these salts being soluble in water. The mantles are made of ramie fiber, which is immersed in the fluid until saturated, then passed through a wringer, carefully dried and shaped, and burned to convert the nitrates to oxides, at which stage the mantle is very delicate, because the fabric of ramie threads has been burned to an ash. The mantle is held together by a coating of collodion, which burns when the mantle is first lighted.

As only a small quantity of cerium is used in the mantle industry, and the monazite contains from 25 to 35% cerium oxide (Ce_2O_3), after the thorium was extracted the residue contained a large amount of what was considered useless rare-earth minerals, and this material being thrown out soon accumulated in large piles. The inventor of the gas mantle, Auer von Welsbach, finally turned his attention to the utilization of this waste material. He reduced it to the metallic state, first by converting the oxides to chlorides and then recovering the metal by electrolysis. The material obtained is an alloy containing all of the different metals in the original waste material, and consists principally of cerium, lanthanum, and didymium. This mixture of metals is known as "Misch metal," "cerium mixed metal," "Auer metal," etc., and has the following composition: Cerium metal, 50%; lanthanum and didymium, 45%; and iron (as impurity), 1%.

Pyrophoric alloy.—The most important use of the above mixed metal is to alloy it with iron to produce what is known as pyrophoric alloy, the sparking metal used in place of matches. Cerium metal is supplied in cylindrical ingots of any desired length. It has to be heavily oiled to prevent loss by oxidation. The pyrophoric alloy consists of 70% cerium metal and 30% iron, the latter being used to harden the soft cerium metal. The cerium metal is melted in crucibles under a fused covering of barium or sodium chlorides. The chlorides are first melted, after which the cerium metal is added in small quantities; and when the crucible is half full of molten

metal, the iron is added in the form of loose coils of wire, until the alloy of 30% iron is formed. The temperature is then raised to 1000° C., the mixture is gently stirred, removed from the furnace, and poured into iron molds halved like a core-box, which make ingots in the form of cylindrical sticks.

Cerium copper.—Cerium metal is also alloyed with copper for use in non-ferrous metals as a deoxidizer. The alloy usually contains 10% mixed cerium metals and 90% copper, but is too expensive at present to find extensive use in connection with non-ferrous alloys.

Also see Miscellaneous Alloys.

THORIUM

This element was named so by Berzelius in 1829. Its chief source, as mentioned in the section on cerium, is monazite sand. As a metal it has never been obtained in a state of purity, an account of its high melting point and the ease with which it combines with oxygen and all the common elements. Only the impure metal has been prepared. It is a dark gray powder with a specific gravity of 11.3. It readily burns in air with great brilliance; as a powder it ignites if crushed or rubbed. According to von Bolton it melts at 1450° C. (2642° F.), but von Wartenburg placed the melting point at 1700° C. (3092° F.). In physical properties it bears some resemblance to platinum, being resistant to acids, dissolving easily only in aqua regia. It is not used in alloys.

FAMILY 4, GROUP B

8. The metals of family 4, group B, are germanium, tin, and lead.

GERMANIUM

This element was discovered by Winkler in 1885, who named it germanium in imitation of the patriotic discoverer of gallium. Germanium is found in small quantities associated

with the ores of silver, lead, copper, cadmium, tin, zinc, arsenic, gallium, indium, titanium, columbium, and tantalum. The metal has been obtained by heating the oxide with carbon in a current of hydrogen. It is a grayish-white metal with specific gravity of 7.25, and a melting point about 900°C . As it is a very rare element it has not been put to industrial use.

TIN

The properties of tin are such that it is hardly replaceable by any other metal—in fact, for tin-plate, solder, and certain alloys, it stands alone. Native tin is a rare mineral. The principal source of the metal is the oxide cassiterite, which contains, when pure, 78.6% of tin. The ore is always associated with granitic rocks. Like gold, tin may exist in lodes or in gravels. Its metallurgy is fairly simple. Tin is found alone, or with arsenic, copper, gold, iron, silver, and tungsten—in workable quantities. Australia, Bolivia, China, Cornwall, Dutch East Indies, and Malaya are the principal producers. The world's output is around 100,000 tons per annum, of which the United States consumes about half, although this country does not actually produce any ore to speak of, yet it reduces to metal some of the Bolivian product.

Commercial tin is never pure; in table 5 are shown analyses adopted by the London Metal Exchange in 1911.

Characteristics of tin.—Chemically pure tin is a white metal with a strong luster. It scarcely oxidizes in moist air, and entirely retains its metallic luster in dry air. It possesses but little tenacity, but is quite malleable, and can be rolled into very thin plates (tin foil). It is highly crystalline, and when bent emits a crackling noise, the so-called "cry," caused by the crystals rubbing against each other. It possesses a peculiar odor. It melts at 450°F . When fused in contact with air it acquires a film of oxide, and at a white heat burns with a bright flame, and is converted into a whitish powder, known as "putty powder," and used in the arts for polishing.

TABLE 5.—*Analyses of tin by brands*

Metals, %	Banka	Billiton	Penang	Singapore	Mt. Bischoff	Prymont
Tin.....	99.950	99.960	99.939	99.870	99.795	99.938
Antimony.	0.007	0.006	trace	0.008	0.150	0.017
Arsenic....	none	none	0.013	0.045	0.063	0.019
Lead.....	trace	none	trace	0.034	0.037	trace
Bismuth...	none	none	none	0.003	0.005	none
Copper....	0.018	0.023	0.016	0.052	0.035	0.022
Iron.....	0.045	none	0.028	0.003	0.042	trace
Silver.....	none	none	none	0.006	trace	none
Sulphur...	none	0.004	0.005	0.008	0.004	0.004

Williams, Harvey & Co.

Metals, %	Irvinebank	No. 1	No. 2	No. 2a	No. 3	No. 4
Tin.....	99.580	99.860	99.560	99.350	99.200	99.941
Antimony.	0.062	0.015	0.166	0.245	0.300	0.011
Arsenic....	0.034	0.040	0.037	0.065	0.037	0.022
Lead.....	0.221	0.004	0.163	0.223	0.396	trace
Bismuth...	0.025	0.005	0.007	0.015	0.007	0.001
Copper....	0.126	0.047	0.050	0.042	0.100	0.020
Iron.....	0.002	0.003	0.005	0.016	0.013	trace
Silver.....	0.018	none	trace	trace	0.014	trace
Sulphur...	0.004	0.006	0.013	0.013	0.006	0.005

Penpoll

Metals, %	No. 1	No. 2	No. 3	Redruth	Th. Goldschmidt No. 1
Tin.....	99.720	98.710	99.300	99.160	99.860
Antimony.	0.118	0.569	0.325	0.176	0.004
Arsenic....	0.054	0.042	0.056	0.053	none
Lead.....	0.041	0.646	0.212	0.177	0.102
Bismuth...	0.007	0.055	0.050	0.017	none
Copper....	0.052	0.103	0.088	0.445	0.043
Iron.....	0.004	0.007	0.002	0.014	trace
Silver.....	0.009	0.015	0.021	0.006	none
Cobalt....				0.012	trace
Sulphur...	0.007	0.004	0.009	0.008	trace

Th. Goldschmidt

Wing Hong & Co.

Metals, %	No. 2	No. 3	Chinese No. 1	No. 2	No. 3
Tin.....	99.460	99.150	99.343	98.662	95.280
Antimony....	0.015	0.122	0.031	0.039	0.381
Arsenic.....	none	0.046	0.040	0.035	0.050
Lead.....	0.425	0.143	0.434	1.035	3.995
Bismuth.....	none	0.112	0.007	0.012	0.020
Copper.....	0.069	0.352	0.052	0.134	0.106
Iron.....	trace	0.007	0.010	0.014	0.026
Silver.....	none	0.006	trace	trace	0.018
Cobalt.....	trace				
Sulphur.....	trace				
Traces and loss.			0.072	0.058	0.116

Unmanufactured tin comes into the market as block tin, grain tin, and in small bars or sticks. Block tin is cast in ingots or blocks in molds of marble; grain tin is made by heating these ingots until very brittle, and then crushing them; but it is sometimes granulated by melting and pouring into water.

Though soft itself, tin possesses a remarkable property of imparting to certain alloys a high degree of hardness.

Uses of tin.—It is also used in its pure state in the chemical industries for containers, worms of stills, and so forth, and in making tin foil for silvering mirrors and for wrapping food products. Cooking utensils are also tinned because the metal is proof against acid liquors. The most important use of tin is for coating sheet iron in making tin and terne plate; the second largest use is in solders; followed by babbitt and bearing metals, and lastly bronze, brass, and tin foil.

Tin plate is made by coating soft sheet-steel plate with tin. The amount of pure tin per square foot of plate equals 0.023 lb.—in other words, the superficial tin coating is from 2 to 2½% of the finished plate. Terne plate is soft sheet-steel plate coated with an alloy of tin and lead containing as a general rule, 32% and 68% of these metals, respectively. Terne plate, on account of its lead content, is not suitable for manufacturing food containers, but it is satisfactory as a roof covering and for similar purposes.

Physical properties of tin

Atomic weight.....	118.7
Principal valence.....	2 or 4
Specific gravity.....	7.298
Specific heat at 0° C.....	0.0559
Melting point, ° C. and ° F.....	232 and 450
Boiling point, ° C. and ° F.....	1600 and 2900
Linear coefficient of expansion.....	0.00002340
Thermal conductivity, silver 100.....	about 15
Electrical conductivity, silver 100.....	about 13
Tensile strength, cast or drawn, lb. per sq. in.....	4000 to 5000

LEAD

This well-known element is found in about 60 different ores, of which only three are of importance, namely galena,

the sulphide; cerussite, the carbonate; and anglesite, the sulphate. Galena contains 86.6% of lead; cerussite, 83.6%; and anglesite 68.3%. Galena is the most important ore; is widely distributed; and nearly always carries silver, from a trace to several hundred ounces per ton.

Galena is used by brassfounders as a flux in making 50-50 lead-copper alloys. It is broken small, mixed with charcoal, and added to the copper.

Galena is not a pure lead sulphide, but is mixed with such impurities as iron, copper, zinc, lime carbonates, zinc sulphides, and gangue (silica, etc.) from which it has to be separated as much as possible before smelting. This is accomplished by crushing the ore, and concentrating the mineral into small bulk by means of jigs, tables, vanners, and oil flotation. The concentrate is then roasted to drive off some of the sulphur, and is then smelted in reverberatory or blast-furnaces—mostly the latter. If rich enough, the ore may be smelted direct.

As a brief outline of the recovery of lead from its ores and concentrates was given under Silver, there is no need to repeat it here, but the following notes may be added:

Much fume is given off by lead-smelting furnaces, and the precipitation of the solid matter carried by it is important, as it consists of about 65% lead sulphate, 26% lead oxide, and 6% zinc oxide. The baghouse method of catching solid particles from the fume has been improved upon by the well-known Cottrell electrical precipitation process; but baghouses are still in use. The dust can be made into paint, or may be briquetted and smelted for its lead content.

Poisonous properties of lead.—Pure lead is a bluish-white metal, soft, and plastic. It can be cut with a knife, and the cut surfaces can be welded by sufficient pressure. A wire 1/10 inch in diameter breaks under a strain of 30 lb. Commercial lead is practically pure owing to the rigid refining it undergoes for the recovery of silver. It is the heaviest of the ordinary metals, and its salts are very poisonous producing the disease known as "plumbism" which attacks workers in lead, lead

oxide or white lead, or those who use the compounds, such as painters, plumbers, and workers in lead-base metals. Even sleeping in newly painted rooms, or breathing the smoke from burning painted wood has been known to cause attacks of severe sickness. In handling lead, its alloys, or salts, common sense suggests such precautions as wearing gloves; and when fumes are present, gas masks; also before eating, to cleanse the hands and face thoroughly. Lead water-pipes are not often found in houses nowadays, but if they are, the water that has stood in the pipes should never be used; it should be allowed to run away until fresh water is reached, as cases of poisoning have been known from the use of water that has stood in lead pipes. Miners, millmen, or smeltermen affected by lead poisoning may be greatly relieved by a weak electric current being passed through them while their feet and hands are in tubs containing an 0.7% salt solution, as practised at the Bunker Hill & Sullivan mine in Idaho (the Clague method).

Applications of lead.—Owing to its power of resisting corrosion by moisture and atmospheric influences, lead is a valuable covering for roofs. It is also used for gutters, ridges, and other building purposes; and for lining vats, tanks, and other chemical apparatus. Sheet lead is made by casting ingots in molds weighing several tons, and passing them several times through rolls, until they weigh about 30 lb. to the square foot. This is then cut, and rolled to the weights required on the market. Large quantities of lead are used in electric storage batteries, pipe, solders, and terne plate. Lead alloys readily with tin, antimony, bismuth, silver, and gold. It has the following properties:

Physical properties of lead

Atomic weight.....	207.20
Principal valence.....	2 or 4
Specific gravity.....	11.34
Specific heat at 0° C.....	0.0310
Melting point, ° C. and ° F.....	327 and 621
Boiling point, ° C. and ° F.....	1525 and 2787
Linear coefficient of expansion.....	0.00002924
Thermal conductivity (silver 100).....	8.5
Electrical conductivity (silver 100).....	8.5
Latent heat of vaporization, calories.....	209
Tensile strength, cast or drawn, lb.....	2600 to 3300

FAMILY 5, GROUP A

9. Family 5, group A includes vanadium, columbium, and tantalum.

VANADIUM

This metal is fairly widely distributed, but in workable quantities only in Peru and Colorado, yet really not much in the latter State. In Colorado the ore is found in sandstone, and in the high sierras of Peru in shale. The treatment of the ore and its reduction to metal is practically in the hands of one American corporation, with several making the alloy ferro-vanadium.

The preparation of vanadium by the electric method proposed by Gin appears to yield the best results. By heating with carbon, the vanadic anhydride, V_2O_5 , is reduced to V_2O_3 . The latter is molded with retort carbon and rosin into the shape of rods, similar to arc-lamp carbons, and used as anodes, while the cathode consists of steel. The electrodes dip in a bath of iron fluoride and calcium fluoride, so that the fluorine formed on the anode combines with the vanadium to form vanadium fluoride, which is converted with the steel cathode to metallic vanadium and iron fluoride.

Vanadium is a brittle, pale gray metal with a silver-white luster, of a crystalline structure, and is non-magnetic. Its specific gravity is 6.02. It does not oxidize when exposed to the air, even at 212° F., and does not decompose water at 212° F. It fuses at 3236° F. When its powder is thrown into a flame it burns, emitting brilliant sparks. The metal is not attacked by hydrochloric and dilute sulphuric acids. It dissolves, with a blue color, in even very dilute nitric acid, as well as in aqua regia.

Vanadium in alloys.—Notwithstanding its high melting point, vanadium readily alloys with other metals—iron for instance. A mixture of ferric oxide, vanadium pentoxide or vanadic anhydride (V_2O_5), and charcoal yields, when heated in an electric furnace, a crystalline regulus of a bluish-white

color, with homogeneous fracture, and containing 72.96% iron, 18.16% vanadium, and 8.35% carbon. With copper, a bronze-colored, malleable alloy with 96.52% copper and 3.38% vanadium is obtained in the same manner. It can be readily drawn out to wire, and is harder than copper. With aluminum, an alloy is obtained by bringing a mixture of vanadium pentoxide and finely pulverized aluminum into a crucible containing liquid aluminum, and stirring. It is known as aluminovanadium, and is used as a deoxidizing agent.

COLUMBIUM

This element was named columbium because it was discovered in an American mineral, by Hattchett in 1801. It bears a close resemblance to tantalum, and is found in the minerals columbite, euxenite and samarskit. This metal has been little studied and at present is of no importance in metallurgy.

TANTALUM

This element, which was discovered by Ekerberg in 1803, occurs in the same minerals as columbium, and in many respects resembles it. One of its ores is tantalite (stibio-tantalite) of which there are fairly large deposits in Western Australia, also some in Rhodesia. The metal is very refractory, darker in color than platinum, and very difficult to reduce from its associated minerals. The melting point of tantalum is placed at 2475° C. (4487° F.) by Tiede and Birnbrauer, and at 2850° C. (5162° F.) by von Pirani. Tantalum is an extremely ductile metal, and when forged and treated with its oxide it is hardened to the same extent as the best hardened steel, but at the same time retaining its toughness. Tantalum is also hardened by the addition of silicon. When carefully hardened it is almost impossible to bore it with a diamond-drill. The metal has not been used to any extent in non-ferrous metals and alloys, but was for a time drawn into extremely fine wire for use as filament in electric light bulbs.

FAMILY 5, GROUP B

10. Included in family 5, group B are nitrogen, phosphorus, arsenic, antimony, and bismuth.

NITROGEN

Nitrogen is a gas, an important constituent of the atmosphere, which contains 79% nitrogen, and 21% oxygen by weight. The name nitrogen was given this gas because it is a constituent of niter. It is a colorless, transparent, odorless, and tasteless gas, which is not poisonous and does not support combustion. It combines with many metals to form nitrides, and whenever aluminum is melted and allowed to heat to beyond a blood-red color, some nitride is formed, and may be detected by the odor of ammonia, which is evolved when the skimmings are wetted with solution of sodium hydroxide. Nitrogen need not be considered further in this work.

PHOSPHORUS

While phosphorus is an element it is not a metal, but is one of the non-metallic substances which unites with metals and greatly modifies their characteristics, and so is an important factor in metallurgy. The compounds of phosphorus are widely diffused and found in nearly all rock materials, in ores of metals, in the soil, in the brain and nerve tissue, and other important parts of the animal organism.

Manufacture of phosphorus.—Bones are largely calcium phosphate, and at one time nearly all commercial phosphorus was made from the calcium phosphate contained in bones. These were first burned, forming what is known as bone-ash, which was crushed and treated with dilute sulphuric acid thereby liberating the phosphoric acid and precipitating the calcium as sulphate, or gypsum.

The phosphoric acid remained in the watery portion and the calcium sulphate was removed by filtration, then the

weak acid was evaporated to a syrup. This was mixed with charcoal and heated to a dull red, converting it into metaphosphoric acid, which was then heated with charcoal in bottle-shaped iron vessels when the phosphorus distilled over, and was condensed in receivers under warm water. The electric furnace is now largely employed in the production of phosphorus, which is obtained from mineral phosphates. These are smelted with sand and carbon at a very high temperature, liberating the phosphorus as vapor, which is collected and condensed to the solid form. Alloys of phosphorus, such as ferro-phosphorus, are made by mixing the mineral phosphate with sand, ground coke, and iron turnings, and melting them together in an electric furnace. The liberated phosphorus enters into combination with the iron, forming what is called an "alloy," which may contain a considerable amount of phosphorus.

There are two kinds of phosphorus—the yellow and the red. The former comes in sticks about 12 inches long and resembles thin wax candles. The red variety is a dull purple-red solid, which does not require to be kept under water, and is much safer to use for adding to metals, but is more expensive than the yellow variety. Both kinds are nothing but phosphorus, and the one form can be converted into the other without loss. The red variety will withstand five times the temperature, when heated in air, than the yellow variety can be exposed to before it takes fire, and therefore, is a comparatively safe form of phosphorus, more particularly as it is non-poisonous, while the yellow product is extremely so. Yellow phosphorus is made from the ores or compounds of phosphorus, while the red phosphorus is made from the yellow phosphorus by heating it to about 250° C., while it is confined in glass or porcelain vessels that can be made air-tight.

Use of yellow phosphorus.—The yellow variety is most commonly used in brass foundries, and being such an active element chemically, special precautions are necessary for its control, it being very flammable. A stick of phosphorus held in the air always appears to emit a whitish smoke, which is

luminous in the dark, this effect being chiefly due to a slow combustion the phosphorus undergoes by the oxygen of the air. Larger quantities of phosphorus exposed to the air become so thoroughly heated by oxidation as to commence to melt and ignite spontaneously. Phosphorus in metals is only possible if ores containing phosphoric acid are used in their preparation, whereby a reduction of the phosphoric acid to phosphorus takes place, which combines with the metal.

Yellow phosphorus comes in sticks about 12 inches long, and is packed vertically in cans filled with water. When the phosphorus is removed from the can, more water must be added, otherwise the ends of the sticks will be exposed and will take fire. The water must always cover the sticks, and the can itself should be stood within a wooden cask, also filled with water, so that in case the can leaks, no exposure of the phosphorus to the air is possible.

To add the phosphorus to copper or bronze, remove the sticks from the container and break them into pieces from 2 to 3 inches long. This is done by holding the stick in one hand and smartly rapping it with a piece of metal, such as the back of a case knife, or with a cold chisel. Drop the broken phosphorus immediately into a dish of water until ready to use. In the meantime the copper has been melted, and if phosphor-copper is required, take an ordinary iron foundry ladle which has been daubed, and is perfectly dry and cool, and place the required amount of the broken phosphorus in the bottom of the ladle.

As soon as the phosphorus is dry it will begin to smoke, when it should be thoroughly covered with finely powdered charcoal. As soon as the phosphorus begins to smoke, the copper is removed from the furnace, and is prepared for pouring by being placed in a secure shank, having long handles, while the ladle containing the charcoal-covered pieces of phosphorus is placed under a hood, or in a place where there is plenty of ventilation, and the molten copper is poured into the ladle on top of the phosphorus. The charcoal covering prevents the phosphorus from burning away, and the loss is

small, as it is absorbed by the metal. This is an excellent and safe method of using stick phosphorus.

As to the amount of phosphorus to use, this is entirely dependent upon the purpose for which the alloy is to be employed. Alloys that must be both strong and ductile must be phosphorized high or low in accordance with their tin content, as the qualities desired can be obtained with high tin and exceedingly low phosphorus; or with low tin and high phosphorus; but not with high tin and high phosphorus, because both tin and phosphorus have much the same effect as hardeners.

On the other hand, bearing alloys with high tin and considerable lead content can be phosphorized freely, and it often happens that with 12% tin and 7% lead it is found expedient to use 1% of phosphorus.

An alloy containing 10% of tin, intended to be tough and strong, will not stand more than 0.1% of 15% phosphor-copper, otherwise its physical properties will deteriorate; while an alloy with 4 or 5% tin will require from 1% and upwards of phosphorus to give the same strength.

Zinc in phosphor-bronze.—Zinc is never added to phosphor-bronze, either for bearing purposes or for strength and ductility, when the phosphor-bronze is made from new metals and a first-class alloy is desired. Phosphor-bronze containing zinc has often been made from scrap metals, but the tin content is always low compared with that of regular phosphor-bronze. The same effect of hardness is produced by the addition of phosphorus as by the addition of tin, only phosphorus is much more effective in this respect. It is used in scrap brass because it produces a cheaper alloy, but the metal has to be handled with great skill, otherwise the castings will be worthless. Given this skill, excellent results can be obtained from the practice of adding phosphorus to miscellaneous scrap. Such metal is exceedingly fluid, and considerable time is required to enable it to cool to the proper casting temperature after removal from the furnace, consequently it is advisable to set the pot near the molds, and to cool with gates until

the metal begins to freeze on the cold gate. It should only form a thin coating, and at this stage the alloy should be handled with celerity, otherwise the castings will be misrun. Heavy risers are required to feed the heavy sections of castings, and the gates must be so placed that the zinc smoke is kept out of the molds.

While phosphorus is extensively used in brass-foundry operations, the use of elementary phosphorus has declined to such an extent that it is a curiosity to see it handled and the ones using it are regarded as being very much behind the times. In place of stick phosphorus, or even red phosphorus, what might be termed "alloys" are used. These consist of copper and phosphorus, and tin and phosphorus, and the former being the most extensively used, on account of its convenience, as it contains up to 15% phosphorus, while phosphor-tin will carry about 5%.

Phosphor-copper and phosphor-tin.—The former alloy comes in two standard grades, namely the 15% and the 10% phosphorus content. The advantage of the 10% alloy is that this amount of phosphorus can be better depended upon than the 15% material; therefore, when a given amount of phosphorus must be found by analysis in any bronze, the 10% phosphor-copper is the more reliable to use.

The manufacture of phosphor-copper is specialized by certain producers who have learned by experience just how to handle the dangerous chemical. One method of making phosphor-copper frequently used is to first melt the copper, then drop the phosphorus in cake form onto its surface, then spear the cakes with a long-handled "phosphorizer," and submerge them in the molten copper. This operation requires special skill to be successful and avoid accidents, and excessive loss of phosphorus.

ARSENIC

This element, like phosphorus, is frequently classed among the metals, it having strongly marked metallic characteristics, such as metallic luster and conductivity for electricity. The

chemical character and composition of its compounds connects it in the closest manner with phosphorus.

Arsenic occurs in nature both native (rare) and in chemical combination with other elements. Native arsenic is sometimes found in the crystalline state, but it generally occurs in rough lumps which readily break up into uneven laminae. More common in nature are its compounds, of which the most important are arsenical iron pyrite or mispickel, smaltite or tin-white cobalt, realgar, and orpiment. Besides these, arsenic is also found in combination with oxygen as white arsenic, and in the form of arsenious acid in various minerals. There are a few small mines in the United States producing straight arsenic ore, but most of the arsenic on the market is a by-product from the flue-dust of copper smelters.

When freshly broken, arsenic possesses a steel-gray color and strong metallic luster. It is very brittle, and may therefore be easily reduced to powder. Its specific gravity is 5.7. When exposed to moist air, arsenic loses its metallic luster and becomes dull in consequence of surface oxidation. When heated in the air it volatilizes and burns, forming white fumes of arsenious anhydride, having a garlic-like odor. Arsenic is used for hardening lead in the manufacture of shot, and some other alloys. However, on account of its extremely poisonous nature its use must be avoided in alloys to be employed in the manufacture of utensils in which food is to be preserved.

ANTIMONY

This metal seldom occurs free in nature and is usually found combined with sulphur. The commonest form is stibnite, the trisulphide (Sb_2S_3). This contains 71.4% metal, and is extracted by the method known as liquation, or heating in crucibles; or by calcining and recovering the antimony as an oxide, which may be used in that form for some purposes, or reduced to the metallic state. China controls the world's supply. A good deal of antimony is recovered as a by-product from lead ores.

Antimony is a lustrous crystalline solid of a bluish-white color, with a specific gravity of 6.62: It melts at 824° F., and crystallizes on cooling in rhombohedra, which give it the name "star" antimony. When slowly cooled its fracture shows large crystalline laminae, but when quickly cooled the fracture is granular. It is volatilized at a bright red heat, and at a white heat may be distilled in a stream of hydrogen gas. It is brittle and can be converted into a fine powder by pounding in a mortar, and, like bismuth, cannot be used alone. It is, however, of importance in the manufacture of several useful alloys—such as type and bearing metals—and possesses the property of increasing the hardness of a metal even if mixed with it only in small quantities.

BISMUTH

This element is only sparsely distributed in nature, and nearly always occurs in the free state, though it is sometimes found associated with sulphur (bismuthinite), copper, lead, and zinc. Bismuth is a by-product from the electrolytic refining of copper and lead. It is grayish-white with a reddish tinge, is brittle, and can therefore be readily powdered, and crystallizes very easily. Its specific gravity is 9.8; it melts at 507° F. It possesses the property of expanding considerably on passing from the liquid to the solid state.

Bismuth being too brittle to be used alone, its chief employment is in the preparation of alloys. Some kinds of type and stereotype metals contain bismuth whereby they acquire the property of expanding in the mold during solidification, and are forced into the finest lines of the impression. Bismuth is also remarkable for its tendency to lower the fusing points of alloys, which cannot be accounted for by its own low melting point. What is known as cliché metal, used in automatic water sprinklers which limit or extinguish fires in buildings, consists largely of bismuth. Bismuth is also employed together with antimony in the construction of thermoelectric piles.

FAMILY 6, GROUP A

11. The elements of family 6, group A, are chromium, molybdenum, tungsten, and uranium.

CHROMIUM

Chromium is a comparatively rare metal, and only occurs in nature in combination with other elements. The principal ore is chromic iron ore, which occurs either in place as small pockets, or several thousand tons in the rock serpentine; or finely disseminated through this rock; or in alluvial form as grain or nuggets. The chromic iron ore contains 68% of chromic oxide, on which basis it is sold. It has a brownish-black color and sub-metallic luster. The metal is obtained by reduction of its oxide or chloride, or by the electrolysis of its chlorides, when chromium separates out in brittle, glistening scales. Its color is tin-white, and it has a specific gravity of 6.92. Chromium melts with greater difficulty than platinum, and is only slowly oxidized when heated in the air. The fused metal is noted for its hardness. Chromium is alloyed with nickel to form the alloy called nichrome. It is also used as alloy for the wires of electrically heated apparatus, in chrome-nickel steel, and to a limited extent in non-ferrous alloys.

Chromium possesses the following properties:

Physical properties of chromium

Atomic weight.....	52.00
Principal valence.....	2, 3, or 6
Specific gravity.....	6.92
Specific heat.....	0.1039
Atomic volume.....	7.5
Melting point, ° C and ° F.....	1510 and 2750
Boiling point, ° C. and ° F.....	2200 and 3992

MOLYBDENUM

The name of this element is derived from the Greek word *molybdos*, meaning lead. The element was isolated by Hjelm in 1782. It occurs chiefly as molybdenite (MoS_2), which bears a strong resemblance to graphite. The latter was at

one time known as "molybdaena," which was modified to molybdenite, and applied solely to the sulphide of molybdenum, after it became known this was a metal and not a different form of graphite. While both molybdenite and graphite are flaky and mark paper, the former, on being heated gives off sulphur, but the graphite does not, and remains unchanged. Molybdenite is found in granite rocks, pegmatite dikes, and quartz, mostly finely disseminated. Its recovery is somewhat difficult owing to its flaky nature. Water or oil flotation is employed. The other commercial molybdenum mineral is wulfenite, which carries lead and less than half the molybdenum that molybdenite does.

Molybdenum is silver-white, and when pure is ductile and can be forged. It is resistant to atmospheric influences at ordinary temperatures, but oxidizes when heated.

Use of molybdenum.—The principal use of this metal is to alloy with steel, for such special purposes as rifle linings, armor-plate, shell steel, permanent magnets, and plate for high-pressure boilers, bank vaults, and other service. It is also used to make high-speed steel. It is added to steel chiefly as ferro-molybdenum, to a smaller extent as an alloy of nickel and molybdenum, but to a growing extent with vanadium and chromium in steel. Molybdenum is a valuable deoxidizing agent in steel. In non-ferrous alloys its high melting point is a stumbling block, as it does not wash down and dissolve in molten copper like some metals, notably nickel. It is necessary to use the pure, soft metal to alloy with copper, as the presence of carbon with iron—as it occurs in ferro-molybdenum—makes it insoluble in that metal, so that it cannot be alloyed even at the temperature of the electric furnace. Molybdenum has the following physical properties:

Physical properties of molybdenum

Atomic weight.....	96.00
Principal valence.....	3, 4, and 6
Specific gravity.....	8.80
Specific heat.....	0.0659
Thermal conductivity at 0° C.....	0.0130
Melting point, ° C and ° F.....	2500 and 4532

TUNGSTEN

The compounds of tungsten are unusually heavy, and from this fact it gets its name, meaning "heavy stone." The metal is never found free in nature, and the ores from which it is commercially obtained are wolfram, ferberite, and scheelite. Of the first mentioned there are three species, namely hübnerite, ferberite, and wolframite. Hübnerite is a manganese tungstate with theoretically 76.3% tungstic (acid) trioxide (WO_3), and 23.4% manganese oxide; ferberite contains 76.3% tungstic trioxide and 23.7% ferrous oxide; while wolframite is a mixture of hübnerite and ferberite. Scheelite is a tungstate of calcium, containing as high as 80.6% tungstic trioxide and 19.4% of lime. Tungsten ores are found in quartzose-granitoid rocks, and sometimes exist with silver, gold, and copper. The straight tungsten ores are fairly easily concentrated. (See U. S. Bureau of Mines Bulletin 187, 1921.)

Characteristics of tungsten.—Tungsten is a heavy, infusible metal, only slowly attacked by any single acid, and not sensibly tarnished in air. It is obtained in powdered form by reduction of the anhydride in a stream of hydrogen at a bright red heat. It is also obtained by reducing the anhydride with carbon in a crucible, but is then so impure that it differs materially from the pure element, being brittle, harder, and less dense. In the pure state tungsten may exist as a powder or an exceedingly ductile metal.

To be ductile it has to be pure, therefore the pure powder produced by hydrogen reduction is the starting point of ductile tungsten. The powder is pressed into rods, which are heated in an electric furnace in an atmosphere of hydrogen to a temperature of 2850°C ., a treatment that produces a brittle, sintered bar, which is worked until it becomes ductile. This process was discovered by W. D. Coolidge. These brittle bars are placed in a sintering furnace where they are subjected to a current of 2750 amperes at 220 volts, single phase. The temperature is maintained in an atmosphere of dry hydrogen, and the body of the furnace is water-cooled. The sintered

bars are then swaged and drawn, while heated. The hammering and rolling (swaging) renders the tungsten ductile; the work is carried out in ingenious machines, at a temperature of 1200 to 1400° C. About fifty successive treatments in this machine are necessary to reduce the diameter of the bar from 6 to 1 millimeter. This hammering and rolling is the secret of ductile tungsten, which is used for filaments in incandescent lamps.

The manufacture of ferro-tungsten is described by J. P. Bonardi and J. C. Williams in Bulletin 187 of the U. S. Bureau of Mines. The electric-furnace plants shown are in Colorado, near the tungsten mines.

Ferro-tungsten.—In the form of ferro-tungsten the element is used in steel alloys. The analysis of a typical ferro-tungsten made by the crucible process follows:

Analysis of crucible ferro-tungsten

	Per cent		
Tungsten.....	61.86	75.38	75.50
Carbon.....	1.17	0.53	0.52
Sulphur.....	0.42	0.40	0.40
Phosphorus.....	0.066	0.043	0.057
Silicon.....	0.48	0.48	0.46
Manganese.....	0.42	0.59	0.38
Iron.....		Remainder	

The physical properties of tungsten are as under, according to various authorities:

Physical properties of tungsten

Atomic weight.....	184.0
Principal valence.....	6
Specific gravity.....	18.77
Specific heat at 0° C.....	0.0336
Melting point, ° C. and ° F.....	3177 and 5751
Boiling point, ° C. and ° F.....	3700 and 6692
Young's modulus of elasticity, kg. per sq. mm. (twice that of steel).....	42,200
Hardness (Moh's scale).....	4.5 to 8.0
Temperature coefficient of resistance.....	0.0051 (0-170° C.)
Tensile strength of 5-mm. wire, lb. per sq. in.....	460,000
Tensile strength of rolled sheets, lb. per sq. in.....	500,000

Tungsten is not affected by dilute sulphuric acid, boiling or cold. Sulphuric acid, boiling, concentrated, attacks very

slowly. Hydrochloric acid, boiling, concentrated, attacks slowly; but neither the strong nor dilute acid affect it at ordinary temperatures. Nitric acid, concentrated or dilute, has no effect. Hydrofluoric, concentrated or dilute, has no effect. A mixture of concentrated hydrofluoric and hydrochloric acids attacks the metal rapidly.

The chief uses of tungsten are in the ferrous alloys; it is one of the important metals in high-speed steels. A feature of these steels are the deep cuts possible in machining, also that the tool-steel needs no lubricant and may become dull red without being dulled. In non-ferrous alloys, tungsten has been little used. Tungsten can be alloyed with aluminum, but confers no special properties thereon.

URANIUM

This element is not found free in nature, and its ores are comparatively scarce. It occurs chiefly as the oxide, U_3O_8 , which equals $UO_2 \cdot 2UO_3$, in the mineral pitchblende. An alloy with iron is made (ferro-uranium) which is used to impart special properties to steel, and as a deoxidizer in a manner similar to vanadium. Uranium is especially notable because from one of its ores, pitchblende, the supply of radium salts is obtained. The study of this heavy element led to the discovery of radioactivity, as it was found to affect a photographic plate in the dark. These particular properties of uranium compounds, however, belong to the province of chemistry and physics.

In non-ferrous metals, uranium has not been used to any extent, and its future in this connection may be regarded as a doubtful one. Its name was derived from that of the planet Uranus. The element has the following properties:

Physical properties of uranium

Atomic weight.....	238.2
Principal valence.....	4 or 6
Specific gravity.....	18.68
Specific heat, at 0° C.....	0.0280
Melting point.....	near that of molybdenum (2500° C.)

FAMILY 6, GROUP B

12. The family group 6B includes oxygen, sulphur, selenium, and tellurium. The two last members of the group need no consideration here as they find little application in industry, and rather appear to be harmful; consequently when found in metals it is necessary to eliminate them during the refining process (electrolytic refining of copper). The first two members of this family group are very important in all metallurgical operations, as it is by working one against the other that they are finally eliminated, and with them other undesirable impurities naturally mixed with the ores.

OXYGEN

Oxygen constitutes nearly 21% of the atmosphere, about 33% of the earth's crust, and nearly 92% of water. It is a very active agent, and with water oxidizes the upper portions of metalliferous veins. It combines with metals to form oxides. Copper has two oxides, one containing twice as much oxygen as the other, and distinguished by a black color, the one with the least oxygen is red in color. These oxides are known as cuprous oxide and cupric oxide. In the former there are two atoms of copper to one of oxygen, expressed as Cu_2O ; and in cupric oxide, there is one atom each of copper and oxygen, or CuO . The first oxide contains approximately 89% of copper, and the other, 78.5%. Cupric oxide forms as a black coating, which may thicken to a scale when the copper is heated. Cuprous oxide exists in copper and is harmful in copper alloys, because it dissolves or mixes with the metal, and remains therein, thus introducing a non-metallic constituent.

Deoxidizers.—The so-called deoxidizers added to alloys in brass-foundry practice consist of elements having a greater affinity for oxygen than for copper, consequently they are supposed to unite with the oxygen in the dissolved copper oxide, liberating the copper into the bath, and removing the

oxygen by forming a slag therewith, which rises to the surface and can be skimmed off. Charcoal and some fluxes are used when melting simply to cover the surface of the molten copper, and keep it from contact with the air and furnace gases.

When yellow brass is poured, the white smoke that fills the air and condenses like little snowflakes is zinc oxide.

SULPHUR

This element is remarkable for its abundant occurrence in nature in the uncombined state. Enormous quantities are recovered from the gypsum deposits at a depth of below 1000 feet in Texas and Louisiana, also from volcanic deposits in Sicily and other places. It is purified by distillation, and then forms a crystalline mass of a characteristic pale yellow color, which melts at 232° F., and at about 780° F. is converted into ruby-colored vapor. By the admixture of organic substances sulphur acquires a black color in melting. The affinity of sulphur for most metals is so great that they combine with it with great energy. If, for instance, copper be thrown into a vessel containing sulphur heated to boiling point, the combination takes place and is attended with vivid combustion. An intimate mixture of iron and sulphur needs only to be slightly heated to effect the union of both elements, which is accompanied by vivid glowing. The combination can even be induced by moistening a large quantity of the mixture with water.

What are known as "sulphides" in mineral deposits are definite chemical combinations of the metals (nearly all) with sulphur. What is termed the "sulphide zone" in a vein is that section where the metal or metals are in the form of sulphides, and below water-level and out of reach of the oxygen of the air. The sulphides make difficult the extraction of some metals.

The combinations of the metals with sulphur are in most cases distinguished by a high degree of brittleness, a small admixture of sulphur being generally sufficient to impart to

them this property. And this property being by no means a desirable one, care should be exercised in making experiments in the preparation of alloys to use only metals absolutely free from sulphur. It may also be remarked that in such experiments the presence of every foreign body exerts a disturbing influence, and in order to obtain satisfactory results it is recommended to use only chemically pure metals.

FAMILY 7, GROUP A

MANGANESE

13. This element has been placed in the same family as chlorine, bromine, fluorine, and iodine. This is known as family 7, and while it includes manganese on account of family resemblances, it is so different to the other members that it is placed in a group all alone. Manganese, therefore, belongs to family 7, group A, while the other members are placed in group B.

Manganese is so intimately associated with iron that it is rare to find one of its ores that does not contain some iron. Other metals, such as lead, zinc, silver, copper, tungsten, and nickel, are also associated, but iron is the most common impurity. There is a great deal more manganese ore in the United States than is generally supposed, but deposits of high-grade ore are usually small; and as the former class is considered to be too low in manganese to make the high-manganese alloys used in the steel industry, it is probable that most of the requirements of this metal will continue to be imported from Brazil, India, and Russia.

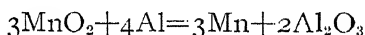
Alloys of manganese.—Manganese is used only to a limited extent in non-ferrous metals and alloys. Its largest use as a metal is in the steel industry. In its Bulletin 173,* the U. S. Bureau of Mines is authority for the statement that about 15 lb. of metallic manganese is added to every ton

* Manganese, its uses, preparation, and mining cost, including the manufacture of ferro-alloys, by C. M. Weld and others, 1920.

of steel at present made. The standard alloys are 80% ferro-manganese and 20% spiegeleisen. As much as 286,000 tons of the former and 193,291 tons of the latter have been made in one year in the United States, mostly from imported ores. The metallic manganese represented by these alloys was 304,000 tons.

Manganese steel.—From 11 to 13.5% of manganese is used in steel as an alloying agent, the product being known as manganese steel. The effect of this addition is to toughen the steel considerably, making it extremely resistant to wear. Manganese steel is also hard, but its chief quality is toughness, which makes it almost impossible to machine, so it has to be ground. It is used for parts of machinery that are subjected to extreme wear and abrasion, such as parts for steam-shovels, grab-buckets, dredge-buckets, crusher liners, rolls, coal mining and breaking machinery, railway frogs and crossovers, magnets, gears, concrete mixers, and even safes. Manganese is a metal that is now indispensable to the steel industry.

Manganese copper.—Manganese is used to limited extent in non-ferrous alloys, and is sold in the form of manganese-copper (30% Mn), manganese-aluminum (25% Mn), and as manganese metal. The metal is obtained by reduction of the dioxide by aluminum, and by carbon. The aluminum reduction proceeds according to the following equation:



The manganese-copper is used as a deoxidizer in gunmetal (from 0.25 to 0.5%); also occasionally for making manganese bronze. (Generally ferro-manganese is used in the manganese-bronze hardener.) Manganese-aluminum is used to introduce manganese into aluminum, in making aluminum alloys.

The metal manganese is used to make manganese-copper and manganese-aluminum. Some grades of manganese-copper are made from ferro-manganese, in which case the alloy will carry considerable iron. The best grade of manganese-copper

must be practically iron-free, consequently the iron alloys of manganese cannot be used in its production.

Physical properties of manganese

Atomic weight.....	54.93
Specific gravity.....	7.42
Specific heat at 0° C.....	0.1217
Melting point, ° C. and ° F.....	1225 and 2237
Electrical conductivity, silver 100	15.75
Weight per cubic inch, lb.....	0.268

When obtained by the thermit process, manganese has a silvery appearance with purple colors on some surfaces; that obtained by other methods resembles cast iron in appearance. It is very brittle. Although the melting point is higher than that of copper, manganese dissolves without difficulty in molten copper, so that alloys of copper and manganese are easily made. When properly used, manganese is one of the most efficient deoxidizers used in the brass foundry.

FAMILY 7, GROUP B

FLUORINE, CHLORINE, BROMINE AND IODINE

14. Family 7, group B, includes fluorine, chlorine, bromine, and iodine. These elements are only used in their combinations in alloying. Fluorine is one of the elements in fluorspar (calcium fluoride, CaF_2), so much used as a flux; and chlorine combined with sodium makes common salt, also used in melting operations. The great affinity of sodium and chlorine has been taken advantage of in the extraction of many elements that are obtained with difficulty. It is frequently comparatively easy to obtain a chloride or a tetrachloride of the element desired, then in the majority of cases this chloride can be decomposed by sodium, with the formation of common salt, leaving the element formerly combined with the chlorine, in the metallic state. When sodium is found unsuitable for the purpose of liberating the desired element, electrolysis may often be resorted to.

Bromine and iodine find little application in alloying. The latter has, however, been passed into mixtures of copper and

lead in a molten state; and it has been claimed that the effect was to keep the lead in suspension in the copper during the period of solidification.

FAMILY 8, GROUP A

15. The members of family 8, group A, are the well-known metals iron, cobalt, and nickel. These three elements have very similar atomic weights, namely, 55.84; 58.97; and 58.68, respectively.

IRON

Sources of iron.—Although one of the most abundant metals, iron is rarely found native or in the metallic state. Its combinations with other elements are so widely diffused though, that it is found in the ash of plants, the blood of animals, and the water of springs. Its ores are chiefly oxides and carbonates. The richest are known as magnetic iron ore (magnetite), and contains 72.41% of iron; and red hematite, an anhydrous sesquioxide, containing 70% metal. A crystalline form of the latter mineral is specular iron ore. Other ores are limonite, or brown iron ore, a hydrated sesquioxide containing 59.89% iron; also yellow ocher and spathic iron ore, or carbonate of iron. Clay iron ore is a mixture of clay and carbonate of iron occurring abundantly in the coal measures. These poorer ores may yield from 25 to 40% of iron. As the sources of the world's supply of iron ore are so well known it is unnecessary to discuss them here.

History of iron.—Iron is generally regarded as the most useful metal known to mankind, and its history dates back several thousand years. The metal has been found in the joints of the stone work of the pyramids in Egypt, which would put the age of that particular piece of iron at from 5000 to 6000 years. Iron was also known to the Assyrians, 2000 years B.C.; while in India the metal was in use about 1600 B.C. In fact, the Hindoos excelled in the working of iron, and produced the most famous sabers in the world.

They were made of what was known as "Indian steel" which was regarded as a very precious metal. The natives of India believed that iron had the power to ward off evil spirits, and erected pillars of iron, which were worshiped with that end in view. The pillar of Delhi is famous the world over. Its dimensions are: height, 23.7 feet; upper diameter, 12.5 inches; lower diameter, 16.5 inches; and weight about 14,000 lb. It is set 20 inches in the ground, and on account of its club shape and weight it is so firmly rooted that the cannon balls of Nadir Shah, while marking it indelibly, could not overthrow it. Another pillar of India is that of Dhar, now overthrown and broken into three pieces. This pillar was about 42 feet long originally, and is a particularly ponderous mass of iron dating back to about the year 320 of the Christian era. Such masses of metal as the huge bells and statues of the Far East carry a message of the wonderful skill and knowledge of these ancient metal-workers that suggests the practice of modesty as a becoming virtue when enumerating modern achievements along similar lines.

Old iron smelting methods.—Iron has also been worked by the uncivilized peoples of Africa since times unknown, and even now in certain regions, the method of smelting iron ores has remained unchanged, probably since it was invented. In figure 18 is shown a number of African iron-founders at work, and figure 19 is a section and plan of a native African iron-smelting furnace, which was one of three found by a British mining engineer in Upper Guinea, West Africa, in the small village of Bobela. These furnaces are circular in section, with walls about 9 inches thick.

The hearth of the furnace is formed by scooping out the earth inside the walls, until a dish is made, as shown, from the lowest point of which a channel is made through the walls, to a depression outside, which constitutes the slag-pit. The furnace is built of clay, and is fitted with a ring of tuyères. The tuyères slant from the outside of the furnace to the center of the hearth. They are made of a mixture of clay and sand, and are thoroughly dried before use. As many as 26 of these

tuyères are used in a single furnace, and they are renewed after each heat. When the furnace is started, a charcoal fire is kindled on the hearth, and the breast, which is an arched opening on the side farthest from the slag-pit, is built up with clay and stones; the slag opening is also blocked, and the furnace is filled with a mixture of iron ore and charcoal. Air passes down the tuyères to feed the fire, and as the latter burns, the tuyères become red hot, thus preheating the air



Figure 18.—Aboriginal Africans making iron (courtesy U. S. Bureau of Mines).

and producing a crude form of hot blast which enables a sufficient temperature to be reached to reduce the iron. The slag is drawn off occasionally, and in 6 or 8 hours the charge is run down and a new one of ore and charcoal is introduced, this process being continued through a run of about 30 hours. At the end of the run, the slag is drawn off, the archway is broken down, and the mass of reduced iron, amounting to 200 or 300 lb. is dragged out and cooled with water. It is a spongy mass of steely iron mixed with slag and charcoal. It has never been molten, but has reached a pasty mass in

the furnace. This spongy material is worked (alternately hammered and heated to free it of slag) into various forms by the native artisans.

This simple and primitive method shows how easily the metal is reduced from the richer ores by heating with charcoal. It is a process requiring little mechanical skill and no chemical knowledge, and is the oldest known method of extracting iron from its ores.

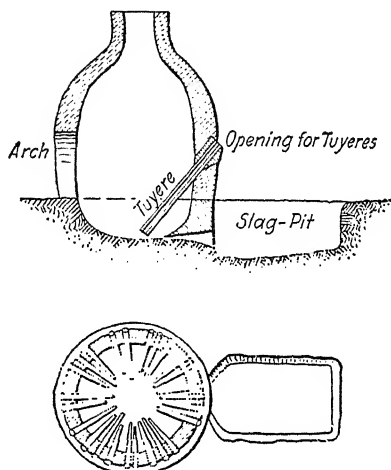


Figure 19.—Section and plan of a native African furnace.

Modern iron manufacture.—In the modern process, the iron ore is smelted in a blast-furnace with limestone as a flux and coke as fuel. The reduced iron collects in the bottom of the furnace, and is periodically tapped out into channels formed in the sand floor of the casting-house—or run into a casting machine—and when solidified the iron so shaped is known as “pig iron,” and consists of about 93% iron, 3 to 5% carbon, and small amounts of silicon, manganese, sulphur, and phosphorus. The iron is graded by analysis and classified according to the method of manufacture. Wrought iron and steel are made from this pig iron. Thus in the manufacture of wrought iron, the pig is melted in a puddling

furnace as it is called—really a reverberatory furnace—and is then manipulated by hand or machinery to remove the carbon and other impurities by oxidation, after which the iron can be gathered into a ball, or bloom, which is further worked by squeezing, rolling, cutting, and welding, until finally it is shaped into bars, known as “muck bars,” which are the starting point for various other operations. Other processes are also used for converting the cast iron into wrought iron and steel. For instance, in the open-hearth or Siemens-Martin process the pig is melted in large furnaces fired by natural, by-product, or producer gas, and the impurities are removed by oxidation and by the lining of the furnace. In the Bessemer process (invented by the late Sir Henry Bessemer), air is blown through the molten pig iron in a converter vessel, and the impurities are oxidized by atmospheric oxygen.

In figure 20 is shown a group of modern American blast-furnaces.

Carbon in iron.—All iron prepared on a commercial scale contains carbon, the purest being wrought iron carrying about 0.15%, steel with 0.15 to 1.5%, and cast iron with upwards of 1.5%. In general it may be said that the properties of the various grades of iron depend upon the varying proportions of carbon present, and hence, in this sense, iron may be considered an alloy with carbon. Silicon and manganese also are sometimes present, not as incidental, but as intentional constituents. The preparation of such varieties of iron, however, belongs more particularly to the metallurgy of iron proper.

Chemically pure iron may be obtained by reducing peroxide of iron with hydrogen at a red heat, or by re-melting the purest varieties of malleable iron with an oxidizing flux in order to remove the last traces of combined carbon. The physical properties of the metal vary considerably according to the means adopted for its production. When obtained by reducing peroxide of iron by hydrogen at the lowest possible temperature at which the change can be effected (according to Magnus between 600 and 700° F.) it forms a dark-gray

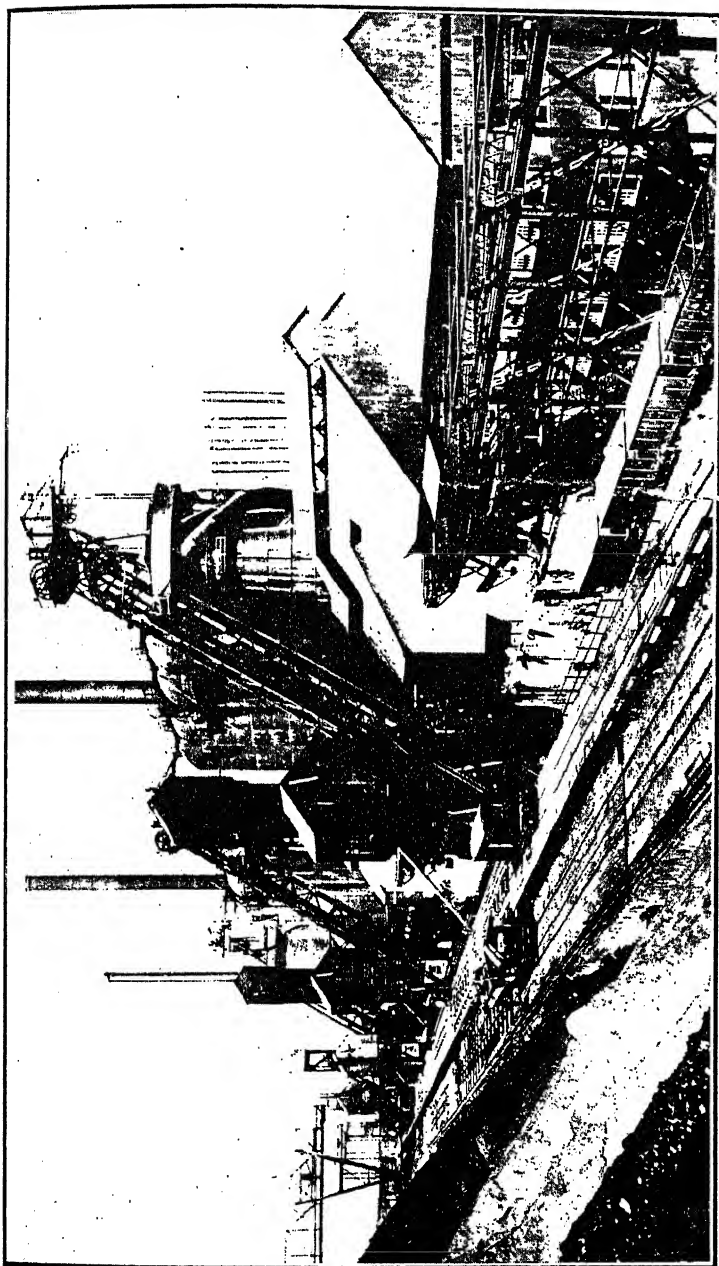


Figure 20.—A modern American blast-furnace plant (courtesy Iron Trade Review).

powder, which combines energetically with oxygen, taking fire spontaneously when slightly heated and thrown into the air. When, however, the reduction takes place at a higher temperature, the metallic powder agglutinates to a sponge of filamentous texture, a silvery-gray color, and metallic luster, which is no longer pyrophoric.

Electrolytic iron.—A very pure iron is also obtained by electrolytic deposition, and is known as electrolytic iron. A concentrated solution of ferrous chloride is electrolyzed at a temperature of 75°C. , using cast-iron anodes and cathodes on a rotating steel mandrel. A current density of 1000 amp. per sq. m., and the use of depolarizers permits smooth, dense iron to be deposited of any desired thickness. Pure iron boiler tubes are made by the above method, which is known as the French process.

Iron oxidizes very readily. In a damp atmosphere rust has a very destructive action (recently this has been termed as simply corrosion), and necessitates the employment of paint and other preservative coatings. In the molten state or at a red heat, iron in contact with the air oxidizes rapidly, and acids attack it and dissolve it with ease.

Iron alloys.—Iron alloys readily and in all proportions by weight with aluminum, antimony, chromium, cobalt, gold, manganese, nickel, platinum, tin, titanium, tungsten, vanadium; and with greater difficulty with larger quantities of copper, though smaller quantities of the latter are readily absorbed by iron, and smaller quantities of iron by copper. It alloys with zinc only in limited proportions. Acicular zinc crystals contained, according to Erdmann, in addition to 93.2% zinc, 6.5% iron, and 0.3% lead. Small prismatic crystals, examined by Abel, contained 7.45% zinc, besides 91.80% iron and 0.75% lead. On the other hand, a more refractory and specifically heavier alloy containing as a rule 3 to 5% iron is formed on the bottom of iron pots in which zinc is for a long time kept molten.

In refining zinc, for which purpose it is kept molten for a considerable period, an alloy is separated which may contain

6.3% of iron; and by dissolving iron in molten zinc heated to a red heat, an alloy with 8.5% of iron may be produced. As the zinc volatilizes on being more strongly heated, it may be assumed that this is the limit of iron which can be taken up by zinc. However, according to Snelus, 12% of iron may be dissolved in zinc if the iron be added in the form of powder, and the solubility is increased by the addition of arsenic to the zinc. With 2.25% of arsenic, the alloy may take up 14.15% of iron.

Iron also alloys only to a limited extent with bismuth, and, under ordinary conditions not at all with lead and silver. In iron blast-furnaces, in which lead-bearing iron is worked, the lead, together with all the silver, is obtained completely separated from the iron.

Steel of all kinds, malleable iron, and cast iron, are alloys of iron; and they are now so many and different that they alone cover a field which requires a lifetime of study. Under the subject of iron alloys the matter will be considered further.

Properties of iron.—The physical properties of iron will vary with the impurities it contains, but those of commercial wrought iron are approximately as follows:

Physical properties of iron

Atomic weight (pure iron).....	55.84
Principal valence.....	2 or 3
Specific gravity.....	7.85
Melting point, ° C. and ° F.....	1520 and 2768
Boiling point, ° C. and ° F.....	2450 and 4444
Specific heat, average for temperatures between 60 and 212° F.	0.1130
This value for the specific heat increases with the temperature up to 1550° F. and then diminishes.	
Linear coefficient of expansion.....	0.000011
Weight per cubic inch, lb.....	0.283

COBALT

This element is generally found associated with nickel and arsenic. Its principal minerals are smaltite, a cobalt-nickel-iron-arsenic compound; and cobaltite, a cobalt-arsenic-sulphur compound. At Cobalt, Ontario, the smaltite is rich in silver. The metal is obtained by roasting and smelting the

ores, and partly purifying them in blast-furnaces; then by a chemical process, cobaltic hydroxide is precipitated, from which the oxide (Co_2O_3) is obtained. From the oxide the metal can be reduced. Cobalt is a white metal with a slight reddish tinge, and is very hard and refractory. Its power of whitening copper is greatly inferior to nickel. It has the following properties:

Physical properties of cobalt

Atomic weight.....	58.97
Principal valence.....	2 or 3
Specific gravity.....	8.7562
Melting point, ° C. and ° F.....	1467 and 2672
Specific heat (mean) between 60° and 212° F.....	0.1053
Linear coefficient of expansion.....	0.00001236
Tensile strength (pure), cast, and annealed, average of 10 melts, lb.....	34,400
Cobalt with 0.062% carbon, tensile, lb. per sq. in.....	59,700
Cobalt with 0.25% carbon, tensile, lb. per sq. in.....	61,900
Percentage of reduction and elongation is greatly increased by carbon, and is over.....	20%
Compressive strength of cobalt; bars $1\frac{1}{2}$ inches long and $\frac{3}{4}$ inch diameter follows:	
Cobalt, cast and unannealed, lb. per sq. in.....	122,000
Annealed cobalt compressive strength, lb. per sq. in.....	117,200
Cobalt with 0.06 to 0.3% carbon, compressive strength, lb. per sq. in.....	175,000
Compressive yield of pure cobalt, annealed, lb.....	56,100
Compressive yield, unannealed, lb.....	42,200
Tensile strength, lb. per sq. in.....	37,900
Brinnell hardness.....	128.7

In many respects, cobalt bears a close resemblance to nickel, but unlike the latter it has no useful application in alloy with copper. It is not used alone, but mainly as an addition to steel, to make alloy steels. It is also employed in enameling metal-ware, giving a similar finish to that of nickel. The protoxide is used in the color industry, the colors prepared from it being much employed in painting glass and porcelain.

NICKEL

This metal was discovered by Cronstedt in 1751, in the arsenide (Ni-As), a copper-colored mineral called *kupfer-nickel* by the German miners. This term means "false copper." This compound, together with the impure arsenide

termed speiss, formed at the bottom of the melting pots in the manufacture of "smalt," constitute the principal sources of nickel in Europe. The largest, and really only commercial deposits of nickel are those of New Caledonia, a French possession in the Pacific Ocean; at Sudbury, Ontario, Canada; and in Norway.

A large amount of accurate and interesting information regarding nickel has been collected in the past two years by Paul D. Merica, superintendent of research, for the International Nickel Co. of Sudbury, Ontario, and published in *Chemical and Metallurgical Engineering* for January 5, 1921. This was reprinted by the company, and the following notes are abstracted therefrom. (Incidentally, it may be remarked that the most comprehensive publication on nickel is "Nickel Deposits of the World," a 584-page compendium issued in 1917 by the Royal Ontario Nickel Corporation. Another handsome and instructive publication is the 12 by 16-inch booklet of 81 pages issued in 1918 by the Mond Nickel Co. of Sudbury, Ontario, which we will refer to under nickel alloys.)

Sources of nickel.—Commercial nickel is found in three types of ores, namely, the sulphides of Sudbury and Norway, the silicates and oxidized ores of New Caledonia, and the arsenical ores of Cobalt, Ontario; Saxony, and elsewhere. The sulphides and silicate ores are the most important, and in addition to these sources, a small amount of nickel is annually recovered by the electrolytic refining of blister copper.

Ore treatment.—The sulphide ores are first roasted, and then smelted in blast-furnaces to a matte containing approximately 24% nickel (plus copper), 45% iron, and 30% sulphur. This matte is next blown in a converter to what is essentially a mixture of nickel and copper sulphides, which is ready for refining. Although the smelting practice of the companies producing sulphide ore of the Sudbury¹ type is essentially the same, as well as the product which is usually known as Bessemer matte. The refining of this matte to metal, and the separation of the nickel and copper are accom-

plished by widely different processes, of which the following three are most important:

Hybinette process.—This process, operated in Norway, is essentially electrolytic. The matte is roasted to remove the bulk of the sulphur, then leached with 10% sulphuric acid, which dissolves a large proportion of the copper, taking very little nickel. The residue is melted and cast into anodes, containing about 65% nickel, and from 3 to 8% sulphur. These anodes are electrolyzed, with cementation of the contained copper by anode scrap. In this manner, nickel anodes and both cement and cathode copper are obtained.

Mond process.—This process, in which the Bessemer matte is first roasted and the copper partly removed by leaching with sulphuric acid, producing copper sulphate solution. The residue, consisting of nickel oxide, copper oxide, and iron, is reduced at a low heat to a finely divided metallic powder. This is carefully protected from contact with air, and carbon monoxide is passed over at a temperature of from 50 to 80° C. At these temperatures nickel-carbonyl vapor is formed, later to be decomposed by passing it through a tower containing shot nickel heated to about 200° C. A layer of nickel is formed on the shot, while the carbon monoxide is regenerated and returned to the volatilizing towers. The nickel shot is alternately exposed to and withdrawn from this gas, and in this way a series of concentric films of nickel are built up around the original shot. These resemble the layers of an onion, and afford a ready means of identification of the metal made by this process.

Orford process.—This process is the oldest method for the separation of nickel and copper, and is in vogue in the United States. The Bessemer matte is smelted with salt cake and coke in a blast-furnace, forming a sodium-sulphide, copper-sulphide matte of low specific gravity. This product is allowed to cool in pots, in which a separation takes place, the upper portion or "tops" containing the greater part of the copper sulphide and the sodium sulphide; the lower portion or "bottoms," contains the greater part of the nickel sulphide.

The tops and bottoms are readily split apart when cold. Several treatments are required to get a sufficiently complete separation. The tops are melted in the copper cupola, then blown in the copper converter to blister copper, and the bottoms, consisting essentially of nickel sulphide or matte, are roasted and leached alternately until completely changed to nickel oxide. This is reduced with charcoal in crucibles or reverberatory furnaces to metallic nickel, the temperature being high enough so that the nickel is sufficiently fluid to be cast into ingots or granulated by pouring into water. Electrolytic nickel is also made by casting this reduced nickel into anodes from the reducing furnaces, then plating out pure nickel from the anodes in an electrolyte of nickel sulphate.

The silicate ores of New Caledonia contain no sulphur. They are first mixed with sulphur-bearing material—such as gypsum or pyrite—and are smelted in a blast-furnace to a matte. This is shipped for refining, which in this case, in the absence of copper, consists merely of roasting the nickel matte to oxide, and reducing the oxide with charcoal.

Commercial grades of nickel.—Nickel appears on the market in the following forms:

1. Grains, cubes, rondelles, or powder reduced at low temperature from nickel oxide and not fused in the process of manufacture.

2. Nickel deposited in concentric layers from nickel-carbonyl and not fused in the process of manufacture.

3. Nickel deposited electrolytically as cathode sheets.

4. Nickel in the form of blocks or shot made by reducing nickel oxide, and pouring the resultant molten metal into water.

5. Malleable nickel made in the same manner as 4, but treated with some deoxidizer before pouring into ingots. This nickel appears in the shape of rods, sheet, wire, and the like.

Most of the commercial production of nickel falls in class 4. The following table (No. 6) shows the grades of material produced by various firms, together with their analyses:

The following grades of nickel can be obtained:

"A" shot nickel, a high-carbon nickel suitable for melting to form anodes for nickel platers.

"X" shot nickel, a purer nickel than "A," and is suitable for making nickel steel and nickel silver.

Ingot or block nickel: This is almost identical in composition with "X" shot. It is sold in 25 and 50-lb. blocks or ingots, and is convenient for the use of makers of open-hearth and electric nickel steel.

Electrolytic nickel.—This product, in the form of cathodes 24 by 36 inches, weighing about 100 lb., or in smaller squares, is used in the manufacture of high-grade nickel silver or cupro-nickel alloys. Malleable nickel intended for rolling into sheets or rods, or drawing into wire, is made in various grades to suit the particular uses. All malleable nickel is treated with some deoxidizer—generally magnesium—before casting into ingots. This removes nickel oxide, the presence of which would interfere with the rolling and drawing operations. Manganese is also added, both to clear the metal and as an alloying element. In general, nickel cannot be rolled or forged without this deoxidizing treatment.

Uses of nickel.—Grades A and C malleable nickel are produced by the International Nickel Co. for rolling into rods and sheets, and drawing into wire.

Grade D malleable nickel is high manganese-nickel having practically the same analysis as grade C (see table 6) except that the manganese varies from 2 to 5%. This is used principally for spark-plug wire to resist the action of high temperatures and combustion gases.

Fully 65% of the nickel produced is used in the manufacture of nickel steel, and about 15% in making alloys of nickel. Coinage and the electroplating industry may absorb from 3 to 5%; while malleable nickel will absorb about 5% of the total production.

Nickel castings.—These castings, which form part of sodium reduction pots, have also found favor as rabble-shoes in calcining furnaces roasting nickel matte. These shoes are

subjected to oxidizing and sulphurous gases at a temperature ranging from 600 to 1000° C., and they will withstand this severe service for 9 months, whereas iron shoes would last no more than 6 to 8 weeks.

Hot-worked nickel.—In hot-working nickel, both the temperature and the condition of the heating flame should be subject to careful control. The temperature for preheating and rolling should be from 1100 to 1180° C. Ingots should not be subjected to temperatures much in excess of this or they will become hot-short. Below this temperature the metal may be too hard to roll properly. The flame used for heating should be as nearly neutral as possible, and a low sulphur fuel (oil) is essential for successful heating.

For hot rolling of bars and rods of the usual cross-sections the same design of rolls as used for steel may be employed. Nickel and monel metal are very easily guide-marked when hot.

Forging nickel.—Nickel is forged more successfully under a hammer than a press, as the slow action of the latter has a tendency to crack it. To soften nickel which has been worked cold, it must be heated to at least 750° C., the minimum temperature of the annealing range, and allowed to remain in the furnace until thoroughly heated throughout. It may be cooled rapidly or slowly as desired, as there is no alteration in the properties of the metal produced by cooling after annealing.

Annealing nickel.—For the commercial annealing of nickel, a temperature of 900° C. should be used, as this will ensure a more thorough and homogenous annealing. Whenever possible, the annealing should be done in tight boxes to prevent formation of oxide, and a little charcoal may be included in the boxes to create a reducing atmosphere, which will reduce any oxide that may form. When so treated no pickling is necessary after the annealing. When pickling must be done, sulphuric acid with some oxidizing agent like ferric sulphate or chromic acid must be used; but it is a slow and tedious process.

Nickel can not be smith-welded owing to the formation

of oxide, which can not be fluxed and parts the two surfaces. The metal may be welded in a reducing atmosphere by the oxy-acetylene torch or by the electric welding process. The latter process is used for welding nickel to iron wire to form tips or points for spark-plugs.

Nickel in bronze.—Nickel is used extensively in bronzes, especially in the eastern United States. Some of these alloys, known as nickel bronze, contain as much as 7% nickel, with 9% tin. Nickel is also used to replace tin in bronze alloys, and a special alloy consisting primarily of nickel, 33%; tin, 33%; and copper, about 30%, with strengthening and deoxidizing agents, is sold to the trade by Alloys & Products Inc., of New York. This alloy is added to yellow brass with advantage, and results in sounder and smoother castings. In brass-foundry alloys, nickel should always be introduced in alloy with other metals forming part of the melt; and the mixture should be properly deoxidized and should carry sufficient deoxidizer to cleanse the alloy to which it is added if the best results are to be obtained. Used in this manner it will affect great improvement in bronze, and will save tin.

Nickel as a substitute for tin.—Tests have been made by the U. S. Bureau of Standards to determine the effect of nickel when used in a bronze in place of an equal quantity of tin, and some very interesting results have been obtained. In place of the bronze (copper, 88%; tin, 10%; and zinc 2%) an alloy of copper, 88%; tin, 5%; nickel, 5%; and zinc, 2% was tested, and gave the following results:

Ultimate strength, lb. per sq. in.....	40,680
Yield point, lb. per sq. in.....	13,050
Elongation, % in 2 inches.....	31.8
Reduction in area, %.....	28.0
Modulus of elasticity, lb. per sq. in.....	17,300,000

With lower tin and nickel and higher zinc, using the alloy of copper, 89%; tin, 4%; nickel, 4%; and zinc, 3%, the following results were obtained:

Ultimate strength, lb. per sq. in.....	39,675
Yield point, lb. per sq. in.....	11,500
Elongation, % in 2 inches.....	31.2
Reduction of area, %.....	31.2
Modulus of elasticity, lb. per sq. in.....	14,900,000

It seems to be fairly well established in modern brass-foundry practice that small additions of nickel can be made to most red brass and bronze alloys with improvement of physical, and in many cases, of acid-resisting properties. Also, that in the case of heavily leaded alloys used for bearing purposes, the addition of about 1 or 2% of nickel can be expected to make a more homogenous alloy; one from which the lead is much less likely to liquefy as the casting solidifies. In the case of yellow brass, also, a considerable improvement is effected by small additions of nickel, when added in properly compounded form, pre-mixed with copper, and carrying a small percentage of a deoxidizer such as phosphorus.

The malleability of nickel allows of its being chased like silver and gold, and with the result of greater luster; while the qualities of brilliancy, hardness, and durability, whether used solidly or in electroplating, make it very suitable for table service.

Toughening nickel.—A simple and successful process of refining and toughening nickel, which is now largely used, was developed by Fleitman. It produces a homogeneous metal, from which castings may be made with much less liability of blowholes than with other methods. The procedure consists in adding to the melted charge in the pot, when ready to pour, a very small quantity of magnesium. The magnesium is added in very small portions at a time, and stirred into the charge. About 1 oz. of magnesium is found to be sufficient for purifying 60 lb. of nickel. The theory of the reaction is that the magnesium reduces the occluded carbon monoxide, uniting with its oxygen to form magnesia, while carbon is separated in the form of graphite. The nickel refined by this method is said to become remarkably tough and malleable, and may be rolled into sheets and drawn into wire. Cast plates (intended for anodes in nickel-plating) after re-heating, can be readily rolled down to the required thickness, which greatly improves them for plating purposes, as they dissolve with greater uniformity in the plating bath. Nickel so heated

may be rolled into sheets as thin as paper, and has been successfully welded upon iron and steel plates.

Nickel alloys completely with copper, iron, manganese, zinc, tin, silver, and cobalt, probably also with gold; and incompletely, or not at all, with lead. Some of the nickel alloys possess properties, which, for certain purposes, render them almost indispensable. The alloys known as argentan, Ger-

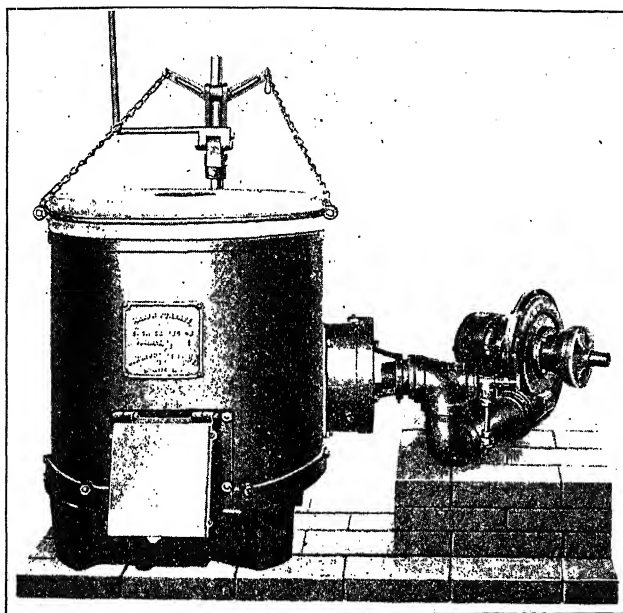


Figure 21.—Gas-fired furnace suitable for crucible-melting of nickel.

man silver, China silver, similor, argent Ruolz, etc., are prepared with the assistance of nickel.

Nickel coins.—Nickel appears to have been used in coins from very ancient times. According to Moulan, Euthydemus, king of Bactria, ordered in 235 B.C. coins to be struck of an alloy containing 77 to 78 parts copper and 22 to 23 parts nickel. Switzerland commenced nickel coinage in about the year 1850, and the United States in 1857.

Melting point of nickel.—As a metal, nickel is melted with difficulty because its melting point is 682° F. higher than that of copper, and only 88° under that of mild steel. A furnace capable of reaching a high temperature is necessary, and while nickel as well as steel can be melted in ordinary coke-fired furnaces of what is known as the pit type, it requires very skillful manipulation of the furnace to get results. An ordinary gas-fired furnace can be expected to attain a temperature of 1400° C. (2552° F.) with air at 2 or 3 lb. pressure, and using illuminating gas. With natural gas in the same furnace, a temperature of 1500 to 1600° C. (2732 to 2912° F.) can be reached, and such furnaces will melt nickel; but they would be slow, and it would be better to increase the air pressure to 10 lb., or over, because with such pressure a temperature of 1650° C. (3002° F.) can be attained with illuminating gas, and up to 1800° C. (3272° F.) when natural gas is used. Figure 21 shows a furnace made by the Maxon Furnace & Engineering Co. of Muncie, Indiana, which has been used successfully for melting metals of high melting point. For high temperature work, gas or oil-fired furnaces, and of course electric furnaces, are the most suitable, as the heat can be continuously applied.

The physical properties of nickel according to several authorities are as under:

Physical properties of nickel

Atomic weight.....	58.68	
Principal valence.....	2 or 3	
Specific gravity, average.....	8.84	
Melting point, $^{\circ}$ C. and $^{\circ}$ F.....	1444 and 2631	
Specific heat, at 150° C.....	0.11509	
Linear coefficient of expansion.....	0.00001279	
	Annealed	Cold rolled
* Yield point of nickel, lb. per sq. in. .	20,000 to 30,000	90,000 to 110,000
Tensile strength, lb. per sq. in.....	60,000 to 90,000	100,000 to 120,000
Elongation in 2 inches, %.....	40 to 50	15 to 20
Reduction of area, %.....	45 to 55	40 to 50
Hardness, according to analysis.		

* David H. Browne and John F. Thompson.

FAMILY 8, GROUP B

16. Family 8, group B, includes ruthenium, rhodium, and palladium.

Ruthenium is obtained from platinum-bearing minerals, and will only be mentioned here. Rhodium is a rare element, and need not be discussed. Its specific gravity is 12.1, and its melting point is 1970°C . It is of interest to foundrymen in its use in the thermocouple of certain pyrometers.

Palladium resembles platinum in appearance, but its specific gravity is about half that of platinum. Its atomic weight is 106.7; specific gravity, 11.4; melting point, 1549°C ., and specific heat, 0.1683. It is a hard, white metal, which does not undergo any alteration on exposure to the air at ordinary temperatures. It occludes hydrogen, resists the action of sulphuretted hydrogen, and is soluble in nitric, hot sulphuric, and hydrochloric acids. Palladium is distinguished from platinum by the fact that an alcoholic solution of iodine evaporated on the metal leaves a black stain. The high cost of the metal prevents any great use, although it is occasionally used in dentistry, in the form of an amalgam for filling teeth. An alloy of palladium and gold known as "palau," has been used in place of platinum for chemical purposes.

FAMILY 8, GROUP C

17. Family 8, group C, contains the elements osmium, iridium, and platinum. The atomic weights of these three elements are very close together, being, 190.90; 193.10; and 195.20, respectively. Iridium is usually associated with platinum. It resembles polished steel in appearance, and is harder and more brittle than platinum, also has a higher melting point. Its specific gravity is 15.9, and melting point, 2250°C . It is used on the points of gold pens, and to harden platinum by alloying therewith.

PLATINUM

This metal is always found in the metallic state in the form of grains and irregular pieces in gravel and sand, and rarely in any ore in commercial quantities. Normally, Russia is the largest producer, followed by Colombia. As a rule it is not pure, but is associated with rhodium, palladium, iridium, ruthenium, as well as gold, silver, chromite, and iron. The only compound of platinum is the arsenide, sperrylite. Platinum has a gray-white color, resembling that of some brands of steel. It is heavier than gold, its specific gravity being 19.32. Platinum is distinguished by its high melting point and great chemical indifference. It is scarcely acted upon by any single acid, but like gold only dissolves in a mixture of heated nitric acid and hydrochloric acid (aqua regia). On account of this indifference and its comparatively great hardness, it is especially used in the manufacture of chemical utensils, it being in this respect without an equal; also in the thermocouples of certain pyrometers.

In a certain respect platinum has some similarity with iron. It can be welded, and readily combines with carbon to a mass with a lower melting point than that of pure platinum. Platinum forms alloys readily, and in any desired proportions with most metals.

Platinum is now rated as one of the precious metals and surpasses gold in value, but for a number of years after its discovery its value was reckoned as less than six times that of silver, and a little more than a third that of gold. Its present value is about five times that of gold, its increased value being due to its scarcity caused by the present condition of affairs in Russia, and the great demand for jewelry made therefrom.

CHAPTER III

ALLOYS: HISTORICAL, FUNDAMENTALS, DEFINITIONS, GROUPS

HISTORICAL

FACTS regarding the development of the art of preparing new metals by melting together several other metals are very meager, and though it appears from several passages in sacred, as well as profane, history that no metallic compound was in more general use with the ancients than bronze, the mode of its manufacture is left in obscurity by historians. Pliny says that a flourishing trade in bronze was carried on in Rome shortly after the founding of that city; and that Numa, the immediate successor of Romulus, formed all the workers in this alloy into a kind of community.

The Greeks possessed considerable knowledge in the art of mixing metals, and knew how to prepare alloys with special properties which rendered them suitable for particular purposes. They understood, for instance, the preparation of alloys which were especially hard, or well adapted for casting. The oldest alloys we know of always contain copper, which is no doubt due to the fact that this metal occurs native in many places, and is also readily reduced from its ores. Next to alloys containing copper, we find those of silver and gold, with a base metal, generally copper.

It is not difficult to explain why the precious metals were alloyed in early times with other metals. On the one hand, these metals were much more expensive than at the present time, and, being subject to considerable wear on account of their softness, it was but natural that some one, recognizing the great similarity between the heavy metals as regards ductility, weight, and luster, should have instituted experi-

ments in order to see how these metals would behave towards each other when melted together. Experience showed that by melting together, for instance, a certain quantity of silver with copper, the properties of silver, especially its white color, were retained, while the hardness and power of resistance of the alloy were considerably increased.

There can scarcely be any doubt that the alloys of copper with tin, generally called bronze, were the earliest mixtures of metals, because zinc, in a metallic state, has only been known at a later period, while tin was known in the earliest historic times. Next in historical order were the alloys of precious metals with each other, and with copper. Mercury, which sometimes occurs free in nature, was also known to the ancients, and its metallic properties recognized by them, as is evident from the name *hydrargyrum* (water-silver), by which it was designated. It is certain that compounds of quicksilver, which, at the present time, are known as amalgams, were used by the Greeks and Arabians. From what has been said, it would seem likely that the ancients understood the art of fire-gilding metallic articles with the assistance of gold amalgam; in fact, some old statues, which had evidently been gilded, have been found—the best example being that of the Roman emperor Marcus Aurelius, which now stands in front of the capital at Rome.

Up to the commencement of the reign of Charlemagne, when the development of the technical arts commenced in Europe, the only mixtures of metals were the alloys of copper, tin, zinc, silver, and gold, and some amalgams. To prepare other alloys a greater knowledge of chemistry was required than that possessed by the early races of mankind. The development of chemistry was principally due to the Arabs, and especially to those that settled in Spain, the Moors, who were well learned in the chemical sciences and in all branches of natural history, and probably well aware of many mixtures of metals still used at the present time. At later periods it was alchemy, the vague hallucination of making gold from lead and other base metals, which prompted men

to undertake investigations fruitful of chemical deductions and promotive of a knowledge of the metals. Many an alchemist found alloys in his crucible, which he threw away dissatisfied because they did not possess the properties of the desired gold, but which at the present time are profitably used. However, it may be said that modern chemistry would not have reached such a degree of excellence if it were not for the abundant facts collected by the alchemist of those times.

FUNDAMENTAL CONSIDERATIONS

When all things are considered, it is evident that an alloy cannot be a mere mechanical mixture of several metals, and hence there remains only the possibility of its being either a chemical combination or simply a solution of one metal in another, similar to a solution of common salt in water, of gold in cyanide, of sulphur in carbon disulphide, and the like.

A chemical combination would seem to be indicated by the development of heat which takes place when certain metals in a fused state are mixed one with the other; further, by the frequent considerable variations in the physical properties of the alloys from those of their constituents (color, specific gravity, fusing point, power of conducting electricity, etc.); by the crystallizing power of many alloys; and finally by the fact that from alloys in a liquid state, when heated but little above the fusing point, solid crystals of varying composition are not infrequently separated—Pattinson's desilverizing process of argentiferous lead, for example. However, it must be remembered that very similar processes also take place in numerous cases with solutions, but with this difference, that solutions are, as a rule, liquid at ordinary temperatures, while alloys, almost without exception, acquire a fluid form only at a higher temperature. On mixing sulphuric acid with water, heat is developed in all cases and with all proportions of weight, without a new hydrate of sulphuric acid being formed every time. The same phenomenon may be observed when absolute alcohol is mixed with water, and in many other

mixtures. However, the physical properties of ordinary solutions frequently vary from those of their constituents in the same manner as we are accustomed to see in many alloys. If common salt be dissolved in water, the specific gravity of the solution is greater, hence the volume smaller than it should be according to calculation if a mere mechanical mixture had taken place. The same phenomenon is also exhibited with solutions of numerous other salts and liquids, of water with alcohol, with sulphuric acid, and many other bodies. On the other hand, it frequently occurs that the specific gravity is less and the volume greater according to the average calculation, this being the case with most solutions of ammonia in water. While the melting point of sodium chloride (common salt) is 1472° F., and that of pure frozen water at 32° F., solutions of the salt in water solidify only at temperatures below 32° F. Numerous other solutions show a similar behavior. However, on slowly cooling a solution of common salt to below the freezing point, a solidified solution poorer in salt is first separated, while one richer in salt remains temporarily behind in a fluid state; and by continuing the cooling, a second separation into a solidifying solution poorer in salt and one richer in salt remaining behind takes places, and so on. This process is used in northern climates for the concentration of salt in sea water, as well as in working poor brine; in fact, it closely resembles the Pattinson process of enriching the content of silver in lead. In this respect, numerous other analogies might be shown—for instance, on solidifying an aqueous solution of alcohol, one poorer in alcohol is first separated, and so on.

From these comparisons it will be seen that the above-mentioned properties of alloys are by no means a certain proof for their being actual chemical combinations; nor is their power of crystallizing always a sure sign of chemical union. Although the crystals of alloys occasionally belong to system of crystallization other than the crystals of each metal comprising the alloys, their composition does not always correspond to definite atomic proportions, but frequently moves

within very wide limits. Thus, gold-tin alloys, with 27 to 43% of gold, crystallize in the dimetric system without a composition according to atomic proportions being necessary therefor. Antimony-zinc alloys, in all proportions of from 30 to 70% of zinc, yield beautifully formed rhombic prisms or octahedrons, etc. As is well known, when solutions, fluid at the ordinary temperature, are subjected to freezing, crystals are formed in them, the composition of which is not always dependent upon chemical atomic proportions, but chiefly upon the solidifying temperature, and hence are nothing but solidified solutions—for instance, solutions of common salt in water, previously mentioned.

The property of many metals, already mentioned, to alloy with each other in all desired proportions by weight, independent of their chemical atomic weight, shows that at least not every alloy represents a pure chemical combination; but that in most cases a solution of one metal in another, or of one or more chemical combinations, in the excess of one of the constituent metals must be present. However, it cannot be doubted that as in the case of other solutions, actual chemical combinations of separate constituents of the alloys are under certain influences formed, and under altered conditions again disintegrated without the nature of the alloy itself being dependent on the presence or absence of such intimate combinations. For example, when copper absorbs oxygen, a chemical combination of both bodies—cuprous oxide, Cu_2O —is formed, which is soluble in the excess of the molten copper, so this solution must therefore be considered an alloy of copper with cuprous oxide. When iron absorbs sulphur, ferrous sulphide, FeS , is formed, and dissolves in the excess of iron. Such cases occur frequently.

The manner of these combinations will depend partly upon the general chemical behavior of the metals to one another, partly upon the proportions by weight in which the metals are present in the alloy, partly upon the aggregate state, and, with alloys in a fixed state, upon the temperature to which they have been heated above these melting points. It is probable

that by strong overheating above the melting point a different grouping of the atoms may, in some cases, take place than by less heating, and that during the transposition into the solid state a change in the mutual relations may again occur. The time of reciprocal action, the manner of mixing, etc., may also be of influence thereby. This explains partly the variations which are frequently observed in apparently the same alloys when prepared in a different manner, heated to different temperatures, or kept in a fluid state for a time of varying duration.

Alloys in a fixed state are therefore essentially solutions of two or more metals one in another. Solutions of metalloids in metals also belong to the alloys, so long as the metallic characteristics—luster, opaqueness, conductivity for heat and electricity—have been preserved. In fact, the boundary between metals and non-metals cannot always be sharply drawn. Many substances that formerly were universally listed among the metals, and which even now are in industrial life called metals, have by reason of their chemical properties been transferred to the non-metals. The conception of the term alloy is therefore a comprehensive one. Lead and tin combine with antimony to form alloys employed for many purposes; arsenical lead, as used in the production of shot, is simply an alloy of the metal lead with the non-metal arsenic. Even iron can, from its behavior, be only considered as an alloy with carbon or silicon.

While some non-metallic bodies dissolve one in another with perfect ease and in all proportions by weight—water and alcohol, calcium chloride and water, ether and alcohol and many others—others possess this property only to a limited extent—water and ether, water and common salt—and still others scarcely dissolve one in another at all, but when mechanically mixed separate again according to their specific gravity, such as water and oil. A similar variation in the power of alloying is also shown by the metals. Some of them alloy readily and in every proportion by weight; others only to a limited extent; and some not at all. However, it depends

also on the temperature, the solubility of the metals one in another being not seldom increased by raising the temperature above the fusing point, though the reverse happens also.

A definite general law for the alloying power of metals towards each other cannot be laid down. Generally speaking, it may be said that metals of a similar chemical behavior alloy, as a rule, with greater ease than when great differences exist in this respect.

Alloys are nearly always formed in a liquid state at a temperature more or less above the ordinary one. At the latter they are solid like the great majority of metals, and it is this property which renders them suitable to be used for numerous useful articles. Many alloys of mercury—the only metal with the exception of gallium which is liquid at ordinary temperatures—however, form an exception. They, like the metal itself, solidify only at temperatures below zero, but any application of them to the manufacture of useful articles has thus far not been found.

For the production of alloys, either all of the constituents may be liquid or only separate ones, the others in a solid state being dissolved in them. Just as a lump of common salt dissolves in water at ordinary temperature—a temperature many hundred degrees below the fusing point of the salt—copper dissolves in molten tin without the latter being heated to the fusing point of the former. Silver in the same manner dissolves in lead, carbon in iron, and so forth in numerous other cases. Combination, however, takes place more rapidly, when both bodies are in a fused state.

It has been mentioned that in combining the constituents to alloys, heat is sometimes developed, the temperature rising suddenly; while in other cases heat is fixed, the temperature being lowered. Development of heat, for instance, takes place in alloying gold with aluminum, and lead with bismuth; while heat is consumed in alloying lead with tin, and, according to Phipson, to a very considerable extent, in alloying 207 parts of lead, 118 of tin, 284 of bismuth, and 1.6 of mercury. The development of heat observed in alloying two metals is

not always a result of this process, but is sometimes caused by incidental processes. For instance, almost all copper contains a fairly considerable quantity of cuprous oxide; and when such copper is alloyed with zinc or aluminum, the cuprous oxide is decomposed, while a corresponding quantity of zinc or aluminum is consumed, and as the generation of heat is thereby greater than the consumption of heat for the decomposition of the cuprous oxide, heat must be liberated.

There are, however, exceptions to the rule according to which alloys are formed in the liquid state. If, for instance, copper is exposed to the action of zinc vapors, the two metals form an alloy, without fusion being necessary. Even two solid bodies may sometimes alloy, without fusion, by intimate contact at a higher temperature, and not only on the surface, but, if the action is sufficiently prolonged, also to greater depths from the surface in consequence of a penetration—a molecular migration—whereby the body entering from the outside is passed from molecule to molecule. The best known process of this kind is the absorption of carbon by low-carbon iron when heated in charcoal or other carbonaceous substances (production of steel by cementation). A similar case is the absorption of iron by nickel when both metals are heated in contact with each other. However, Spring has shown that by mixing the bodies in the form of a fine powder, and exposing the mixture to a very strong pressure, it is sometimes sufficient to combine them to an actual alloy.

DEFINITIONS

The word “alloys” suggests combinations of different metals, such as copper, tin, lead, zinc, antimony, nickel, and others. As a general rule, we do not apply the word to iron and steel, because we have become accustomed to speak of these metals as “cast iron” and “malleable iron;” and “cast steel,” “tool steel,” “carbon steel,” and “alloy steel.” Also, we generally lose sight of the fact that the various kinds of iron and steel are alloys of iron, and that as a consequence

the term alloys is an all embracing one, and includes admixtures of metals which are not confined to a base of copper, exclusively, but may also have iron or any other metal as a base. It is necessary, therefore, to qualify the word alloys, and this has been done in recent years by adding the adjectival prefix "non-ferrous," when referring to metals having a base other than iron. This term is derived from the Latin *non*, meaning not, and *ferrum*, iron. Ferrous means made of, or pertaining to iron. Therefore, non-ferrous means "not ferrous" or "not iron"; consequently, alloys of copper, tin, lead, zinc, aluminum, and others, are non-ferrous alloys because they have a base of some metal other than iron.

Non-ferrous metals.—The following metals are generally considered as being included under the term non-ferrous:

Metals considered as non-ferrous

Aluminum	Gallium	Molybdenum	Strontium
Antimony	Germanium	Nickel	Tantalum
Barium	Glucinium	Palladium	Tellurium
Bismuth	Gold	Platinum	Thallium
Cadmium	Indium	Potassium	Thorium
Calcium	Iridium	Rhodium	Tin
Cerium	Lanthanum	Rubidium	Titanium
Caesium	Lead	Samarium	Tungsten
Chromium	Lithium	Scandium	Uranium
Cobalt	Magnesium	Silicon	Vanadium
Columbium	Manganese	Silver	Zinc
Copper	Mercury	Sodium	Zirconium

Some of the elements listed as non-ferrous metals are too active chemically to be used in foundries for making castings, either alone or a base of alloys; but some of them find application for removing oxygen and other impurities from other metals and alloys.

Purity of commercial metals.—The purity of commercial metals varies with each metal, depending upon how difficult it may be to separate the impurities from the ore before it is reduced—as in the case of aluminum—or whether the metal can be obtained by electrolytic deposition—as in the case of copper, zinc, and other metals. In the case of copper, as detailed in Chapter II, the ore is first concentrated, then passed through roasting and smelting operations which produce an impure copper. This is cast into anodes which are

dissolved in a plating tank, the copper being deposited in a state of great purity on specially prepared cathodes, while the impurities drop to the bottom of the tank to form a sludge or slime, from which the various metals can be recovered by special treatment. By these operations copper is obtained in a high state of purity. Aluminum is always less pure, being recovered with under 1% of impurities. Other metals contain smaller or larger quantities of one or more foreign metals. Thus commercial iron will contain carbon, sulphur, silicon, phosphorus, manganese, and sometimes other metals. These impurities, however, are usually in too small amount to be harmful, and they would be very difficult and costly to remove.

Metals changed by alloying.—By alloying a metal with one or more other metals its properties may be changed in a remarkable manner—for instance, the fusing point may be lowered, and the hardness and strength greatly increased. Hence, by properly alloying a metal, its properties may be so affected as to render it more suitable for the purpose for which it is to be used, injurious properties may be decreased, and desirable ones increased. This is the reason why gold, silver, copper, lead, tin, and other metals are actually more rarely worked in a pure, than in an alloyed state.

Non-ferrous alloys may be grouped into eight classes, in which each has a different metal as the base—that is, the alloy will consist of a certain metal with small additions of other metals. Thus an alloy of 90 lb. copper and 10 lb. of tin is considered a copper-base alloy, the copper being the main part of the alloy. There is no standardized list of such alloys, one arrangement being as good as another, so the following order will serve as an illustration:

GROUPING OF ALLOYS

Class 1. Aluminum alloys.—This consists of alloys with aluminum as a base, and is placed first merely because aluminum commences with the first letter of the alphabet.

Class 2. Bronzes.—These are alloys of copper and tin, which are considered strictly bronze; alloys of copper, tin, zinc, and lead, frequently known as “composition”; alloys of copper, zinc, tin, and lead, known as red brasses; and alloys of copper, lead, and tin known as “plastic bronzes.”

Class 3. Brasses.—These alloys are composed mainly of copper and zinc, and comprise what is known as yellow brass, manganese bronze, tobin bronze, delta metal, muntz metal, and all copper-zinc alloys, either cast or wrought.

Class 4. Nickel alloys.—Included in this class are alloys that contain sufficient nickel to produce a white color, known as nickel silver, German silver, monel metal, and the various resistance and acid-resisting alloys containing a substantial amount of nickel.

Class 5. Tin alloys.—This comprises alloys having a base of tin, and includes babbitt metals, Britannia metal, pewter solders, and all alloys containing a substantial amount of tin.

Class 6. Lead alloys.—These alloys consist largely of lead, and are known as antifriction and type metals.

Class 7. Amalgams.—Compounds of mercury with other metals, and largely used for dental purposes.

Class 8. Alloys of precious metals.—These comprise gold alloys, silver alloys, and platinum alloys.

Class 9. Fusible alloys.—These consists of alloys of tin or lead with cadmium, bismuth, antimony, etc., and distinguished by possessing low melting points, which fits them for special purposes.

Class 10. Iron alloys.—Comprise alloy steels, cast iron, and ferro-alloys.

Class 11. Magnesium alloys.—A comparatively new series of alloys, combining low specific gravity with considerable strength.

Class 12. Zinc alloys.—Alloys having a base of zinc are extensively used for die castings; also for bearing purposes, examples of which are white bronze, cothias metal, and Fontainmoreau bronzes.

The largest proportion of the alloys in class 1 are made

with copper and aluminum, or with copper, zinc and aluminum; however, any or all of the metals listed as non-ferrous may be found in alloy with aluminum. Some of the alloying agents now used were at one time considered very injurious, as in the case of silicon in aluminum, but which is now used in considerable amount. The magnesium alloys in class II are recent additions to the ranks of casting alloys.

Alloys easily cast.—Perhaps the bronzes or the imitation bronzes are the best casting alloys, as they run into the molds fluidly and produce good-looking castings. The brasses in class 3 are more difficult to cast because the large proportion of zinc causes them to fume strongly. This fume is liable to enter the molds and condense there, producing defects which may cause the rejection of a comparatively large number of castings. On account of this increased casting difficulty, such alloys, though costing intrinsically less than the alloys known as red brass, may cost more, as castings and are less favorably regarded by foundrymen.

Brasses misnamed bronzes.—Alloys that are strictly brass are sometimes known by the term “bronze,” as in the case of manganese bronze. This alloy is a brass, because it is fundamentally an alloy of copper and zinc, while true bronzes are alloys of copper and tin. There is no good reason why alloys of copper and tin should be called bronze exclusively; but there must be some distinction between brass and bronze, and it is customary to regard alloys of copper and zinc as brass, and alloys of copper with tin as bronze. Alloys of copper as a base, and aluminum as the alloying metal, are known as aluminum bronze, and are just as true bronzes as the alloys of copper and tin exclusively. Alloys of copper, zinc, and aluminum are aluminum brasses, and thus the aluminum bronze without zinc is distinguished from the alloys containing considerable zinc.

Nickel alloys.—There is a bewildering number of alloys in which nickel is used, some of them contain as much zinc as a yellow brass. They are known as “German silver,” or “nickel silver,” the appellation silver being applied because

they have some resemblance to the precious white metal. There are also other nickel alloys containing little or no zinc, sometimes with considerable percentages of nickel, and sometimes with only a small amount of nickel, with other metals as tin, lead, etc. These alloys may be known as nickel bronzes, or may be given any name by those who make them. Alloys containing copper, nickel, and zinc could be termed "nickel brasses." Properly speaking, this is the name they are entitled to, but such terms as German silver and nickel silver have been applied for so many years, and are so thoroughly understood, that it is doubtful if anything but confusion would ensue by changing them; therefore, these well-known terms will be employed in this work in order that there will be no danger of being misunderstood.

Tin-base alloys.—These alloys melt and cast easily, because the metal tin is not strongly active in a chemical sense like magnesium. When melted, it does not take fire and burn with vivid combustion, but lies quietly and runs very fluidly, and shows no excessive shrinkage during solidification. The chief tin alloys are known as babbitts, and usually the word genuine is prefixed as "genuine babbitt." This is taken to mean an alloy of tin with hardening metals such as copper and antimony, but containing none of the cheaper metal, lead. Other tin-base alloys are Britannia metal and pewter, also the soldering alloys.

Lead-base alloys.—Alloys in which lead predominates are largely used for bearing purposes, and are known as anti-friction metals. Under the head of lead alloys come the various type metals, such as electrotpe metal, monotype metal, and stereotype metal; also the alloys used for cheap die castings, which are mainly lead hardened with antimony.

Zinc-base alloys.—There are a number of alloys in which zinc is the predominating metal. In general, these alloys are hard and lack ductility, and resemble cast iron. They are used for various purposes, such as bearings and for making die castings.

Antifriction metals.—Under the subject of lead alloys, the

term "antifriction" has been used. The word *anti* means "opposed to," therefore antifriction means opposed to friction. Friction may be considered as meaning rubbing, or the force that grips and stops a moving body—revolving shafting, for example. Antifriction metals are better adapted for bearings because they let the shafting slip around, and do not grip or "freeze" onto it, as frequently is the case with metals that are not slippery by nature.

Antifriction metals are bearing metals, and this term is sometimes applied indiscriminately to all alloys that make good bearings, irrespective whether they have a base of copper, or of tin, or of lead. As this leads to confusion, it is desirable to confine the word to alloys having a base of lead. The tendency to do this is steadily growing; also to apply the word babbitt to alloys having a base of tin. This practice differentiates between the costly and the inexpensive antifriction metals, and thus avoids misunderstanding. Both babbitts and antifriction metals have their own particular place in industry; thus the tin-base alloys are distinguished by their toughness, and can withstand heavy pounding, and on account of this property can be used in places where the lead-base alloys would be worthless, for while lead is soft it is not tough. In cases where there is little pounding or pressure on the part of revolving shafting, the lead-base alloys are satisfactory and their use effects considerable saving. The greatest economy in the use of babbitts and antifriction metals is obtained when the proper places for each are thoroughly understood; then the expensive tin-base alloy will not be used where the cheap lead-base alloy would be just as good, if not better.

CHAPTER IV

CHARACTERISTICS OF ALLOYS

It will be understood from the preceding chapters that the properties of the metals vary considerably, and that few possess properties in common. It will next be necessary to consider the changes which certain metals undergo by melting together or alloying.

LIQUATION

When a solution, fluid at the ordinary temperature, is allowed to cool below its congealing point, the process frequently takes place in such a manner that as cooling progresses certain constituents of the solution congeal first, while the solution still remaining liquid undergoes constant changes as regards its composition until the latter remains constant, when this solution also congeals. The solution congealing last is called the "eutectic" (most fluid) solution. However, on examining the congealed eutectic solution more closely it will be found that during cooling a disintegration of the constituents previously dissolved one in another has taken place, and that the solution now forms only an intimate mixture of these constituents. When the temperature is raised, the mixture again combines to the eutectic solution, which, with a further increase in the temperature re-dissolves the previously crystallized bodies.

If, for instance, a solution of common salt containing 3.8% salt be allowed to cool, ice is formed at -3.25°C . (26.5°F .), free from common salt, and the solution becomes richer in common salt. The formation of ice at this temperature continues till the solution contains 5.5% of common salt. If, however, the temperature becomes lower, formation

of ice again takes place; and the solution becomes richer until at a temperature of -22°C . (-7.6°F .) the eutectic solution with 23.5% of salt remains behind, when ice is no longer separated and the whole congeals, disintegrating, however, into an intimate mixture of salt and ice. The entire congealed mass consists therefore of the previously formed ice crystals mixed with the finally congealed eutectic solution. If, however, a solution containing more than 23.5% salt be subjected to cooling, the salt crystallizes, and the solution becomes poorer until at -22°C . (-7.6°F .) it has again acquired the composition of the eutectic solution, and freezes as such. In this case the congealed mass consists therefore of the eutectic solution with imbedded salt crystals.

Many alloys show a similar behavior on cooling. The proof of this is furnished by a metallographic examination—that is, by grinding a sample of an alloy, polishing it, and also treating it with chemicals; or by oxidizing it by heating, whereby the constituents assume different colors. The surface thus treated is then examined under the microscope.

If, for instance, a melted silver-copper alloy* containing more than 72% of silver be allowed to cool, silver crystals are first separated, while an alloy poorer in silver still remains liquid. This separation of silver is continued until the content of silver has been reduced to 72%, which takes place when the temperature has fallen to 1404°F . This is the eutectic point, and the eutectic alloy which now, previous to congealing, no longer separates any constituents but solidifies throughout at that temperature, consists, therefore, of 72 parts silver and 28 parts copper. In congealing it disintegrates, however, to an intimate mixture of its constituents, which on re-heating, first dissolve again in one another, and with increasing temperature gradually dissolve the previously separated silver. By heating the polished surface of such an alloy rich in silver, the copper oxidizes and can be plainly distinguished from the non-oxidized silver when examined

* Melting point of pure silver, 1700°F .; and pure copper, 1983°F .

under the microscope. When, however, an alloy contains less than 72% of silver and more than 28% of copper, as it congeals the copper separated first, until at 1404° F. the composition of the eutectic alloy has again been reached and the latter also congeals.

The alloys of lead and tin, the eutectic alloy of which contains 31% lead and 69% tin and congeals at 356° F., behave in a similar manner; also the alloys of lead and antimony, the eutectic alloy of which consists of 87% lead and 13% antimony, and congeals at 477° F.; so do numerous other alloys. Those containing three or more constituents also congeal, as a rule, not uniformly; and single constituents are first separated until the eutectic alloy which congeals last of all remains behind. It is, however, more difficult to recognize the processes taking place thereby than with alloys of two constituents.

It may also happen that instead of the separate metal, a definite chemical combination crystallizes from the congealing alloy, as for instance, according to Le Chetelier, the compound SbCu_2 from copper-antimony alloys.

This disintegration of an alloy homogeneous in a liquid state is called "liquation." In metallurgical processes this action is sometimes taken advantage of in separating a metal or an alloy richer in precious metal from another metal or alloy (Pattinson's process for extracting silver from lead). However, in working metals, liquation is always troublesome, and should be avoided as much as possible. Since the physical properties of an alloy—strength, ductility, hardness, color, etc.—are closely related to its average composition, and as a slight change in the composition frequently produces not inconsiderable variations, the properties of a piece of metal solidified with liquation will not only be different and less suitable for the intended purpose than would be the case with uniform solidification; but in various parts of the same article variations will show themselves, which may injure its usefulness or render it worthless. Generally speaking, liquation shows itself the plainer, and the variation in the composition of

the alloy becomes the greater, the slower the process of cooling the fused alloys is effected. Hence, rapid cooling of an alloy while solidifying is an effective means of preventing liquation, or to limit it to a slighter degree. The property of liquation, however, does not show itself to the same extent in all alloys. In some it is so strong that it cannot be avoided, even with as rapid cooling as possible, while others show scarcely a trace, even with slow cooling.

Liquation of copper-tin alloys.—Most copper-tin alloys show a distinct tendency towards liquation, which generally increases with the proportion of tin. When such alloys are permitted to cool slowly—as exemplified by the cooling of heavy bronze castings in a sand mold—the alloy does not suddenly congeal and become solid, but the change comes about gradually. Some constituent of the alloy solidifies first and forms the starting point of crystals, and the remaining portion of the liquid metal will then solidify in layers around this core or nucleus, forming a structure somewhat similar to that of an onion. The part to solidify first will naturally have the highest melting point, because it contains the most copper, and subsequent additions to the solid mass will contain an increasing amount of the more fusible tin, until a point is reached when no further separation can occur, and an alloy rich in tin and of comparatively low melting point remains, and must occupy whatever space has been left after the more quickly solidifying layers have taken position. Usually, this more fusible constituent has to fill the interstices between the crystals, and under some conditions of cooling not thoroughly understood, it may happen that there are more voids between the crystals than can be filled by the remaining fluid portion. In such a case it will seep between the heated crystals to fill up portions in a lower part of the casting, leaving voids between the crystals of other parts. Upon machining away the sand-chilled surface of the casting, the drained areas are exposed; and while the lack of solidity is not visible to the unaided eye, liquids and gases under pressure easily pass through, and the casting leaks, and must be dis-

carded. Thus valves with heavy flanges attached to the body frequently leak at the juncture of flange and body owing to the draining away of the liquid metal from between the crystals of metal at this point by the heavy, slow-cooling flanges.

If the flanges can be chilled so that the entire casting congeals at the same time, there will be no loss from leaks. Unfortunately this is a most difficult thing to do, and would be liable to reduce the output to a point where it would be an economy to abandon the chilling method and put up with the loss incident to the usual method of molding.

In some instances this difficulty has been overcome successfully by the adoption of most unusual methods, as in the case of the Muntz Metal Co., Limited, as described by H. Gingell of that company before the Birmingham Local Section of the British Institute of Metals. The method adopted to avoid "segregation" is to chill the castings with water, immediately after they are poured. This is done by making the cores in a special manner, which allows cold water to be poured into them through a funnel about three minutes after the metal has been poured, and while it is still liquid. Taking the case of a heavy bronze nut, the core would consist of an iron tube or barrel, having small openings. About two or three minutes after casting, water was poured through a funnel into the core. The water passed through the vent-holes in the barrel, and oozed through the sand surrounding the same against the metal. The water cooled the nut and prevented it from reaching the temperature at which the different parts of the alloy began to separate. In that way a perfectly sound casting was obtained. The metal thickness of the nut would be about 3 inches, and the length of the core about 6 inches. It was considered important to keep the tube constantly full of water while the casting was cooling. When this was done the casting was sure to be sound.

The casting of a metal roller, 4 feet long and 12 inches in diameter, and cored, was also described by Mr. Gingell. Inside the core was placed a barrel similar to the one in the

nut. It was perforated to carry off the vent and to permit the water to pass through. The casting was molded in a vertical position, risers being put on sufficiently high to feed the casting automatically—that is, without the foundry method of pumping. In constructing the mold, a belt of ash was placed in the sand at a proper distance from the exterior surface of the casting, and a pipe communicated with this belt, enabling water to be applied to the external surface of the casting, as well as to the interior through the core.

The water was poured down into the core three minutes after the metal had been poured; but no water was poured into the mold itself until after the lapse of 30 minutes. The water poured into the mold percolated through ash, and so into the sand surrounding the casting. The water in the center caused the casting to shrink towards the center, while the chilling effect of the water on the outer part of the casting where it was heaviest prevented segregation at that part. By this means a casting was produced which was absolutely sound, and showed no trace of segregation in any part. To prevent segregation, the casting must be constantly cooled with water. It was the contention of Mr. Gingell that without such chilling precautions they would have in a casting of that design and weight separation of the tin with a certain amount of copper (tin sweat), which was a serious difficulty. In some cases it had been known to ooze into the cores and fill them up with a hard mass of metal which required drilling out.

In using the water-chilling method, the core must be made with a view to running water therein as soon as the metal was poured, waiting an interval of two or three minutes; but after the pouring of water had once commenced it must be continuous by keeping the pipes full, otherwise if the water was allowed to sink down the metal would enter the vents. On the outside of the casting, however, it was not wise to commence pouring the water until 30 or 40 minutes after the casting had been poured.

The method of preventing changes in the cast metal due

to slow cooling just described is not a new one, as cannon—both cast iron and gun-metal—were at one time made by a similar method. It was not unusual for as much as 250,000 to 300,000 lb. of molten metal to be poured into molds in which cannon were cast. The guns were cast upright, were cored out in the center, and a steady stream of water under pressure was kept flowing through the core, not only during the time it was being poured, but for several days thereafter, until the casting solidified and cooled. The object of the water-chilling was to increase the density of the metal, which was effected by causing the casting to solidify from the center to the outside in layers, each layer shrinking onto the previous one. No great flight of imagination is required to appreciate the disastrous consequences that would have attended the leaking of water through the core during the pouring period.

The cores were made of loam, swept up on a solid barrel. The core barrel was tightly wound with hay rope, over which was swept two or three coats of loam. The core was vented by grooves planed in the barrel, and which extended its entire length. The cores were sometimes steadied at one end by a depression in the bottom of the mold, or by an anchor; but cores from 16 to 20 feet long have been suspended in molds for muzzle-loading guns without any support other than a tripod at the top. The castings were usually gated from the bottom, using two sprues, and the mold was built up in flask sections, corresponding closely to the shape of the cannon. The flask had to be exceedingly strong to withstand the pressure of from 125 to 150 tons of molten metal at the bottom of a mold 40 feet deep.

The core arbor was also unusually strong, and at the bottom it was several inches thick. The water flowed through a pipe in the center of the arbor, being connected at the upper end to the water supply, while the lower end terminated several inches from the bottom of the arbor. The water flowed downwards through the pipe, emerging in a strong stream from the bottom into the core arbor, up which it passed

at the rate of 45 gallons per minute. The upper end of the core arbor was so connected that the water could flow away continuously; and in spite of the tremendous amount of heat radiated to the core from the mass of metal surrounding it, the water flowing from the arbor was not warmed appreciably, owing to the rate of flow maintained.

The method adopted with these large guns could be applied without danger to heavy bronze castings, and would be an improvement on the method of pouring the water into the core through a funnel.

In making heavy bronze castings to withstand pressure it will always pay to study methods that can be applied to solidify the heavy sections quickly, and prevent the "beta" solid solution from changing over into "eutectoid," which change takes place at a temperature of 500° C. or 932° F.

Adhesion of the crystals of metals.—When in the solid state, most metals and alloys consist of crystals of varying size and shape strongly bound together, but it is not known with certainty just what causes the crystals to adhere to each other.

The theory advanced by Beilby in about 1903 was that the crystals are cemented together by a portion of the metallic substance that fails to form crystals itself, but is distributed around and between the crystals and cements them into one solid mass. This is known as the amorphous cement theory, and in the case of steel it is supposed by the adherents of this theory that the steel exists in two different states, or phases as it is termed. These are the amorphous phase and the crystalline phase, which are formed as the steel cools and crystallizes, the size of the crystals being inversely proportionate to the rate of cooling. When the crystals come together, some steel encased between them is unable to form part of the crystals, but remains in the uncrystallized or amorphous state, and acts as a cement to hold the crystals together into one solid mass. This amorphous cement is supposed to be stronger than the crystalline steel, and thus accounts for the fact that as it breaks, the steel fails to do so

along the boundaries of the crystals, but fractures right through the crystals.

This peculiarity of metals was well discussed by J. A. Van Den Broek, instructor in engineering mechanics in the University of Michigan, in the course of a paper presented before the British Iron and Steel Institute. As explained by him, when steel is cooled rapidly the crystals are smaller, and as a result the cement is much greater in quantity, and being stronger than the crystals themselves, accounts for the fact which is well known, that the elastic limit of steel is much greater when it has been rapidly cooled than when it is allowed to cool slowly.

As bronze and other copper alloys act in a manner very similar to steel when reverting from a liquid to a solid state, and are much alike in structure—as far as being composed of crystals is concerned—the subject is of great interest to all who work in metals; therefore, while steel is specifically mentioned in the paper quoted the conclusions drawn are also applicable to brass and bronze, especially aluminum bronze.

To quote further, crystalline steel can be transformed into amorphous steel even when in the solid state. This is done by working the metal, or by stressing it. When a steel specimen is stressed increasingly, a point is reached in time where the large crystals begin to divide into smaller ones. This breaking up of the crystals marks the elastic limit of the steel, and if there are parting lines in the crystals—or as they are termed “cleavage planes”—the division of the crystal will occur at these points, just the same as a mold is opened at the joint, where a parting is made. These cleavage planes are known as “slip bands,” and as the crystals are not all pointed in one direction—or to express it scientifically, “different crystals are differently oriented”—it follows that some of them are so situated that they are in position to resist the strain better than others, with the result that the ones unfavorably oriented break first, and the others hold until the strain becomes greater. The internal work expended upon the metal while being strained transforms some of the

crystalline metal into amorphous metal. This amorphous metal is plastic at first, but hardens later; therefore, when a specimen is stressed soon after cold-working, there is a constant yielding of the amorphous metal under a permanent stress, which makes the specimen as a whole yield more or less. When a specimen is strained soon after it has been cold-worked, and in a direction opposite to the direction of cold-working, while the newly formed amorphous cement is still plastic, the specimen will yield in a very pronounced way. The amorphous cement hardens in time, this being aided by the gentle application of heat; and if after being cold-worked, the steel is "aged" ("matured" has been suggested as a better word than "aged") for 15 minutes in boiling water, the cement is hardened, and the metal has a higher elastic limit than the original elastic limit.

When steel is polished it is cold-worked, as this operation consists of successive stages of grinding and scratching with an abrasive harder than the steel. The ultimate result is a mirror face that even under a strong microscope does not reveal any scratches. Sometimes, after the surface of the steel is dissolved or etched slightly with chemicals, scratches will show, indicating that they were merely covered over with something; which according to Beilby, Bengough, and others, is amorphous steel worked up on the surface of the steel by the polishing operations. When first produced this amorphous steel is like a viscous liquid, and it will flow and smooth over small cracks and scratches, and thus produce a thin layer of non-crystalline steel over the face of the metal. If this amorphous cement is stronger than crystalline cement the polished steel ought to be stronger than unpolished steel, and to test this theory Mr. Van Den Broek conducted a number of tests with cold-ground and highly polished steel balls, which gave surprising results. The steel balls were produced by forging, heat-treating, rough grinding, emery grinding, and polishing. As a result of 200 tests, which consisted of crushing the balls, which were 1 inch in diameter, it was found that the rough-ground balls were 25 per cent weaker than the

polished balls. When the polish was dissolved from the surface of the balls by boiling for 20 minutes in a solution of 25% hydrochloric acid, the crushing strength of the balls was decreased 32 per cent. When ground balls and polished balls were treated with the acid, the strength of both was the same, indicating that the reduction of the crushing strength in the case of polished balls was not due to the effects of the acid, but to the removal of the layer of amorphous cement from the surface of the balls.

This interesting result would indicate that there is considerable truth in the theory of an amorphous cement existing between the crystals of metals, which binds them together, and is capable of being worked to the surface when the metal is operated upon by polishing and other operations.

Copper-zinc alloys possess little or no tendency towards liquation, and in this respect are favorably distinguished from the copper-tin alloys.

Copper-lead alloys show strong tendency towards liquation. From cupriferous lead, the lead may, by careful heating, be melted out, the copper remaining behind in the form of so-called copper-thorns.

Silver-copper alloys, as previously explained, show strong tendency towards liquation, a fact which is of considerable importance in the use of such alloys for coins, rendering the preparation of blanks of uniform composition more difficult. As previously pointed out, the eutectic silver-copper alloy consists of 72 parts silver and 28 parts copper. In alloys with more than 72% silver, the content of the latter increases towards the center of the casting, while in alloys poorer in silver the content of copper increases in that direction. In an alloy with 69.5% silver, the upper cross-sections are, as a rule, richer in copper, and the lower richer in silver.

Gold-copper alloys with from 23.7 to 92.5% gold, show, according to Levöl, scarcely any sign of liquation after actual alloying of the two metals has taken place; however, to effect this, especially with alloys richer in gold, several re-meltings and frequent stirring are required.

Gold-silver alloys show no tendency towards liquation after actual alloying has taken place.

Lead-silver alloys possess strong tendency towards liquation, as shown by the use made of this behavior in the Pattinson process. Levol found the content of silver considerably greater in the center of the cast and solidified alloys.

Zinc-tin alloys also show considerable liquation, especially when the zinc predominates.

SPECIFIC GRAVITY

The specific gravity or density of alloys corresponds only in a few cases with that which would result by calculation from the specific gravities of the constituents—that is, with the specific gravity which a purely mechanical mixture of the constituents would possess. In some cases the specific gravity is lower than that calculated, expansion having taken place in alloying. More frequently it is higher than that found by calculation, condensation having taken place. Sometimes an alloy possesses a higher specific gravity than that of its separate constituents.

Expansion—that is, decrease in the specific gravity—has been observed in copper-silver alloys, and lead-silver alloys with less than 30% silver; also in tin-antimony and lead-antimony alloys. Condensation has been found in alloys of copper with tin; copper with zinc with between 35 and 80% zinc; lead with gold; tin with silver, etc. An example of a particularly strong condensation may serve the copper-tin alloy with 38% tin, its specific gravity being 8.91, while that of copper was found to be only 8.89 and that of tin 7.31.

Specific gravity of alloys.—Many comprehensive investigations regarding the specific gravities of alloys have been made, but the results must be accepted with caution, because as is well known, the specific gravity of every metal varies between wide limits, and is dependent upon the manner of its previous working and treatment. Hence, for every experiment, not only the specific gravity of each separate metal used has to be accurately determined, but care must also be

taken to avoid as much as possible all sources of error, which may readily arise from the presence of gas bubbles or small hollow spaces in castings, by either converting the metals into a fine powder, or by getting rid of the hollow spaces by mechanical means previous to determining the specific gravity. With alloys, in consequence of liquation, the specific gravity varies in different places of the casting. Some investigators have committed an error in finding the calculated specific gravity by assuming it to be the arithmetical mean between the numbers denoting the two specific gravities—in other words by multiplying the percentage weight of each constituent by its specific gravity, adding the results and dividing by 100. The specific gravity should be calculated from the volumes, and not from the weights. The correct rule is as follows: *

Multiply the sum of the weights into the products of the two specific gravity numbers for a numerator, and multiply each specific gravity number into the weight of the other body, and add the products for a denominator. The quotient obtained by dividing the said numerator by the denominator is the truly computed mean specific gravity of the alloy. Expressed in algebraic language, the above rule is

$$M = \frac{(W + w)Pp}{Pw + pW},$$

where M is the mean specific gravity of the alloy, W and w the weights, and P and p the specific gravities of the constituent metals: †

Of the determinations of the specific gravities of alloys the following have been selected as the most reliable:

The determinations of the specific gravities of copper-tin alloys made by Riche and Thurston‡ are given in table 7. Riche determined the specific gravity with the assistance of

* Ure's Dictionary, vol. 1, page 49.

† Report on a Preliminary Investigation of the Copper-tin Alloys. Washington, 1879.

‡ Loc. cit

metallic shavings, which, to expel air enclosed between them, were boiled in the flask serving for the determination of the specific gravity. Thurston used small pieces as free from flaws as possible, and weighing from $1\frac{3}{4}$ to $2\frac{1}{2}$ oz. each. These pieces were cut from a bar previously used for determining the strength. To cleanse them, they were first washed in alcohol, then dried and boiled two or three hours in water to expel the air enclosed in the pores; and after allowing them to cool in the vessel used for boiling, were brought under the receiver of an air-pump to remove completely any particles of air remaining. The samples were then put quickly into a beaker filled with distilled water, in which they were weighed, being suspended by means of a very fine platinum loop to the beam of the balance.

The numerical values found for the same alloys show considerable variations, but comparing the results obtained as a whole, they agree in many important points. Both series show that when small quantities of tin are added to copper, the alloy, as might be expected on account of the smaller specific gravity of tin, becomes specifically lighter than copper; but as soon as the tin content exceeds 10%, the decrease in the specific gravity becomes less with an increasing content of tin than it should be according to calculation—that is, with an increasing tin content the alloys show an increasing condensation (contraction). From an alloy with 20% onward, this condensation increases to such an extent that the specific gravity of the alloys increases instead of decreases with the increasing content of tin, until, according to both series, it reaches the maximum in the alloy with 38.3% tin (SnCu_3), and then gradually approaches again the specific gravity according to calculation. According to Thurston's series, the condensation is so considerable that alloys with 22.5 to 38.29% tin are specifically heavier than pure copper, while, according to Riche, the specific gravity of one alloy only (SnCu_3), exceeds that of copper. Alloys with less than 10% tin show, according to Thurston, slight expansion, as well as, according to Riche, alloys with less than 16% copper.

TABLE 7.—Specific gravity of certain copper-tin alloys

Composition of alloys			Specific gravity							
Copper	Tin	Atomic formula	According to Riche				According to Thurston			
			Found	Calculated	Difference		Found	Calculated	Difference	
					Expansion	Contraction			Expansion	Contraction
100.00	.....	Cu	8.89	.....	.....	.....	8.791	.....	.....	.....
98.10	1.90	SnCu ₉₆	.....	.....	.....	.....	8.564	.....	.....	.....
97.50	2.50	.....	.....	.....	.....	.....	8.511	.....	.....	.....
96.27	3.73	SnCu ₉₃	.....	.....	.....	.....	8.649	8.712	0.063	.....
92.80	7.20	SnCu ₈₄	.....	.....	.....	.....	8.604	.....	.....	.....
92.59	7.50	.....	.....	.....	.....	.....	8.684	.....	.....	.....
90.00	10.00	.....	.....	.....	.....	.....	8.669	8.614	.....	0.055
89.00	11.00	SnCu ₇₈	8.84	8.69	.....	0.15	8.648	.....	.....	.....
87.50	12.50	.....	.....	.....	.....	.....	8.681	8.534	.....	0.147
86.57	13.43	SnCu ₇₂	8.87	8.60	.....	0.27	8.792	.....	.....	.....
84.33	15.67	SnCu ₆₈	8.84	8.54	.....	0.30	8.740	8.444	.....	0.296
82.50	17.50	.....	.....	.....	.....	.....	8.917	.....	.....	.....
81.15	18.85	SnCu ₆₂	8.72	8.50	.....	0.22	8.565(?)	.....	.....	.....
80.00	20.00	.....	.....	.....	.....	.....	8.925	8.318	.....	0.607
79.02	20.98	SnCu ₅₈	8.72	8.46	.....	0.26	8.932	.....	.....	.....
77.50	22.50	.....	.....	.....	.....	.....	8.938	8.250	.....	0.688
76.32	23.68	SnCu ₅₂	8.62	8.40	.....	0.22	8.907	.....	.....	.....
72.91	27.09	.....	.....	.....	.....	.....	8.947	.....	.....	.....
72.50	27.50	.....	.....	.....	.....	.....	8.956	.....	.....	.....
70.00	30.00	.....	.....	.....	.....	.....	8.970	8.150	.....	0.820
68.25	31.75	SnCu ₄₂	8.75	8.32	.....	0.43	8.781	.....	.....	.....
67.50	32.50	.....	.....	.....	.....	.....	8.682	.....	.....	.....
65.00	35.00	.....	.....	.....	.....	.....	8.643	7.999	.....	0.561
62.50	37.50	.....	.....	.....	.....	.....	8.560	.....	.....	.....
61.71	38.29	SnCu ₃₈	8.91	8.21	.....	0.70	8.442	.....	.....	.....
57.50	42.50	.....	.....	.....	.....	.....	8.446	7.893	.....	0.419
56.32	43.68	Sn ₅ Cu ₁₂	8.15	8.04	.....	0.11	8.312	.....	.....	.....
52.50	47.50	.....	.....	.....	.....	.....	8.437	.....	.....	.....
51.80	48.20	SnCu ₂₂	8.15	8.04	.....	0.11	8.302	.....	.....	.....
47.95	52.05	Sn ₇ Cu ₁₂	8.06	7.93	.....	0.13	8.182	.....	.....	.....
47.50	52.50	.....	.....	.....	.....	.....	8.101	7.755	.....	0.258
44.63	55.37	Sn ₂ Cu ₃	8.06	7.93	.....	0.13	8.013	.....	.....	.....
42.50	57.50	.....	.....	.....	.....	.....	7.948	.....	.....	.....
41.74	58.26	Sn ₃ Cu ₄	7.90	7.79	.....	0.11	7.915	.....	.....	.....
39.20	60.80	Sn ₅ Cu ₅	.....	.....	.....	.....	7.835	.....	.....	.....
37.50	62.50	.....	.....	.....	.....	.....	7.774	.....	.....	.....
34.95	65.05	SnCu	7.90	7.79	.....	0.11	7.770	7.566	.....	0.214
28.72	71.28	Sn ₄ Cu ₃	.....	.....	.....	.....	7.690	.....	.....	.....
27.50	72.50	.....	.....	.....	.....	.....	7.657	7.487	.....	0.170
24.38	75.62	Sn ₅ Cu ₃	7.59	7.58	.....	0.01	7.543	.....	.....	.....
22.50	77.50	.....	.....	.....	.....	.....	7.552	7.443	.....	0.109
21.18	78.82	Sn ₂ Cu	7.59	7.58	.....	0.01	7.487	7.415	.....	0.072
17.50	82.50	.....	.....	.....	.....	.....	7.417	.....	.....	.....
15.19	84.81	Sn ₃ Cu	7.44	7.50	0.06	.....	7.360	7.346	.....	0.014
12.50	87.50	.....	.....	.....	.....	.....	7.342	.....	.....	.....
11.84	88.16	Sn ₄ Cu	7.31	7.46	0.15	.....	7.305	.....	.....	.....
9.70	90.30	Sn ₅ Cu	7.28	7.43	0.15	.....	7.299	.....	.....	.....
7.50	92.50	.....	.....	.....	.....	.....	7.293	.....	.....	.....
4.29	95.71	Sn ₁₂ Cu	.....	.....	.....	.....	.....	.....	.....	.....
2.50	97.50	.....	.....	.....	.....	.....	.....	.....	.....	.....
1.11	98.89	Sn ₄₈ Cu	.....	.....	.....	.....	.....	.....	.....	.....
0.55	99.43	Sn ₉₆ Cu	.....	.....	.....	.....	.....	.....	.....	.....
....	100.00	Sn	7.31	.....	.....	.....	.....	.....	.....	.....

By heating certain copper-tin alloys to a red heat and tempering in water; and the reverse, by re-heating and subsequent slow cooling, the specific gravity is changed in a

remarkable manner. From a series of experiments made in this direction, Riche obtained the following results (specific gravities):

Alloys with 20.80 per cent tin

	I	II	III	IV	V	VI	VII	VIII	IX	X
Cast.....	8.787	8.858	8.825	8.862	8.863	8.780	8.715	8.822	8.842	
Tempered....	8.823	8.915	8.863	8.896	8.906	.....	.....	.....	.....	8.747
Annealed.....	8.817	8.907	8.847	8.886	8.894	8.808	8.739	8.844	8.863	
Tempered....	8.849	8.927	8.871	8.907	8.922	.....	.....	.....	.....	8.871

Alloys with 18 per cent tin

	I	II		I	II
Cast.....	8.737	8.873	Annealed.....	8.753	8.889
Annealed.....	8.733	8.863	Tempered.....	8.775	8.926
Tempered.....	8.763	8.911	Tempered.....	8.786	8.927

From a cast block weighing 4 lb., four bars each weighing about $4\frac{3}{4}$ oz. were cut and used for the following experiments:

Alloys with 20 per cent tin

	I	II			
Tempered.....	8.704	8.719	Annealed.....	.752	8.686
Annealed.....	8.712	8.728	Tempered.....	.780	8.713
Tempered.....	8.730	8.747	Annealed.....	.777	8.714
Annealed.....	8.724	8.744	Tempered.....	.804	8.736
Tempered.....	8.756	8.763	Annealed.....	.815	8.750
Annealed.....	8.741	8.759	Tempered.....	.841	8.774
Again annealed	8.751	8.769	Again tempered	.850	8.787
Tempered.....	8.775	8.792	Annealed.....	.807	8.760

These experiments show that the specific gravity of copper-tin alloys with 18 to 21% tin is progressively increased by repeated tempering, while annealing has a contrary, but less powerful effect—that is, the decrease in the specific gravity produced by annealing is unable to equalize the increase by tempering, so that by alternate tempering and annealing a constant average increase in the density remains

perceptible. The limit above which a repetition of annealing produces no effect has not been determined.

The increase in the specific gravities of the above-mentioned alloys by tempering may probably be closely related to liquation decreased by rapid cooling, and the decrease by annealing to liquation promoted by slow cooling.

Alloys poorer in tin, in which liquation, as a rule, is less perceptible, show, however, a different behavior. By repeated tempering and annealing, Riche found the following specific gravities:

Alloys with 12 per cent tin

Tempered.....	8.625	Annealed.....	8.635
Annealed.....	8.632	Tempered.....	8.632
Tempered.....	8.624		

Alloys with 10 per cent tin

	I	II	III	
Cast.....	8.564	8.677	8.684	8.491
Tempered	8.516	8.635	8.657	8.428
Annealed.	8.528	8.643	8.670	8.431
Tempered	8.532	8.645	8.671	8.437
Annealed.	8.536	8.648	8.674	8.434
Tempered	8.529	8.648	8.673	8.436
Annealed.	8.526	8.643	8.676	8.436
Tempered	8.526	8.626	8.664	8.436

Further the same alloy:

	V	VI		V	VI
Cast.....	8.541	8.705	Tempered.....	8.505	8.693
Annealed.....	8.491	8.689	Annealed.....	8.479	8.651
Tempered.....	8.495	8.684	Tempered.....	.....	8.661
Annealed.....	8.504	8.692			

Alloys with 6 per cent tin

	I	II	III		I	II	III
Cast.....	8.537	8.519		Tempered..	8.502	8.496	8.802
Tempered..	8.491	8.492	8.807	Annealed...	8.507	8.495	8.804
Annealed...	8.501	8.491	8.806	Tempered..	8.505	8.496	8.809

A glance at the above tables shows that, as in alloys richer in tin, an increase in the specific gravity cannot be obtained by repeated tempering and annealing, but that rather a decrease takes place; and that in some cases the effect of one tempering results in a decrease of density, and of annealing in an increase. Further, the poorer the alloy is in tin the sooner the limit is reached at which further treatment of the alloy produces no change in the specific gravity.

By mechanical working—hammering, pressing, and rolling—the specific gravity of copper-tin alloys is increased.

Copper-zinc alloys.—By experiments conducted in the same manner as with copper-tin alloys, Riche obtained the results shown in table 8 following:

TABLE 8.—*Composition and specific gravity of certain copper-zinc alloys*

Composition of alloys			Specific gravity			
Copper	Zinc	Atomic formula	Found	Calculated	Difference	
					Expansion	Contraction
100.00	.....	.....	8.890			
90.65	9.35	ZnCu ₁₀	8.834	8.707	.....	0.127
85.34	14.66	ZnCu ₆	8.584	8.602	0.018	.....
79.51	20.49	ZnCu ₄	8.367	8.489	0.122	.....
65.98	34.02	ZnCu ₂	8.390	8.345	.....	0.045
59.26	40.74	Zn ₂ Cu ₃	8.329	8.119	.....	0.210
49.23	50.76	ZnCu	8.304	7.947	.....	0.357
39.27	60.73	Zn ₃ Cu ₂	8.171	7.783	.....	0.388
32.66	67.14	Zn ₂ Cu	8.048	7.679	.....	0.369
19.52	80.48	Zn ₄ Cu	7.863	7.478	.....	0.385
10.82	89.18	Zn ₅ Cu	7.315	7.351	0.036	.....
.....	100.00	Zn	7.200			

Similar figures were obtained by Calvert and Johnson. While with an increase in zinc content a steady reduction in the specific gravity seems to take place, alloys with 40 to 80% zinc show a considerable contraction.

A series of experiments similar to the above mentioned with copper-tin alloys made by Riche show (1) that the specific gravity of copper-zinc alloys richer in zinc (35%) is increased by mechanical working as well as by tempering;

such increase, however, being largely and occasionally almost entirely, equalized by annealing; and (2) that the specific gravities of alloys poor in zinc (9%) are not affected by such treatment.

Copper-silver alloys.—Karmarsch has determined the specific gravities of copper-silver alloys in coins to remove the influence of porosity, and found the values given in table 9 following:

TABLE 9.—*Composition and specific gravity of certain copper-silver alloys*

Composition of alloys		Specific gravity			
Silver	Copper	Found	Calculated	Difference	
				Expansion	Contraction
100.0	.....	10.547	.....	.....	.....
94.4	5.6	10.358	10.399	0.041	.....
89.3	10.7	10.304	10.351	0.047	.....
81.0	19.0	10.164	10.203	0.039	.....
75.0	25.0	10.065	10.098	0.033	.....
66.3	33.7	9.927	9.951	0.024	.....
62.5	37.5	9.870	9.890	0.020	.....
56.25	43.75	9.761	9.786	0.025	.....
51.21	48.79	9.679	9.706	0.027	.....
49.65	50.35	9.650	9.681	0.031	.....
42.43	57.57	9.532	9.568	0.036	.....
36.7	63.3	9.439	9.482	0.043	.....
33.3	66.7	9.383	9.430	0.047	.....
30.4	69.6	9.333	9.386	0.053	.....
29.5	70.5	9.317	9.371	0.054	.....
22.4	77.6	9.203	9.269	0.066	.....
22.0	78.0	9.190	9.264	0.074	.....
.....	100.0	8.956	.....	.....	.....

The series throughout shows expansion, it being most pronounced in alloys richest in copper, then decreases regularly to the alloy with 37.5% copper, and from there on increases again with increased silver content. Nevertheless the greatest expansion does not attain the same extent as that in copper-tin and copper-zinc alloys.

Copper-gold alloys.—Roberts has determined the specific gravities of some alloys richer in gold in the form of blanks, and obtained the values as shown in table 10 following:

TABLE 10.—*Composition and specific gravity of certain copper-gold alloys*

Composition of alloys		Specific gravity			
Gold	Copper	Found	Calculated	Difference	
				Expansion	Contraction
100.00	.....	19.3203			
98.01	1.99	18.8335	18.8355	.....	0.0030
96.88	3.12	18.5805	18.5804	.....	0.0001
95.83	4.17	18.3562	18.3605	0.0043	
94.84	5.16	18.1173	18.1378	0.0205	
93.85	6.15	17.9340	17.9301	.....	0.0039
92.20	6.80	17.7911	17.7956	0.0045	
92.28	7.72	17.5680	17.6087	0.0407	
90.05	9.95	17.1653	17.1750	0.0097	
88.05	11.95	16.6082	16.8047	.....	0.0015
86.14	13.86	16.4832	16.4630	.....	0.0202
.....	100.00	8.725			

According to the above table, neither regularly progressive expansion nor contraction takes place. In most cases the difference between the found and calculated specific gravities is extremely small, and hence it may be supposed that there is no change in volume—at least, not in the alloys examined. For practical purposes this is of importance in so far as it permits the calculation of the gold content in a gold coin from its specific gravity.

Silver-gold alloys.—Determinations by A. Matthiessen gave results as shown in table 11.

Hence, in alloying the two metals, contraction, though to an inconsiderable extent, takes place throughout.

Tin-lead alloys.—Long found the results as shown in table 12.

All the tin-lead alloys examined show expansion, the maximum being reached with lead content of about 80%. Pillichody obtained similar results, only he found considerably greater expansion (minimum 0.29 in the alloy SnPb₄; maximum in the alloy SnPb). Kupffer, Thompson, as well as Calvert and Johnson, found expansion throughout.

Bismuth-lead alloys.—According to Carty, these alloys gave results as shown in table 13.

TABLE II.—Composition and specific gravity of certain silver-gold alloys

Composition of alloys			Specific gravity			
Silver	Gold	Atomic formula	Found	Calculated	Difference	
					Expansion	Contraction
100.0	.....	Ag	10.468			
76.5	23.5	Ag ₆ Au	11.760	11.715	.....	0.045
68.7	31.3	Ag ₄ Au	12.257	12.215	.....	0.042
52.3	47.7	Ag ₂ Au	13.432	13.383	.....	0.049
35.4	64.6	AgAu	14.870	14.847	.....	0.023
21.5	78.5	AgAu ₂	16.354	16.315	.....	0.039
12.0	88.0	AgAu ₄	17.540	17.493	.....	0.047
8.3	91.7	AgAu ₆	18.041	17.998	.....	0.043
.....	100.0	Au	19.265			

TABLE 12.—Composition and specific gravity of certain tin-lead alloys

Composition of alloys			Specific gravity			
Tin	Lead	Atomic formula	Found	Calculated	Difference	
					Expansion	Contraction
100.0	.....	Sn	7.924	.....	.....	.....
77.0	23.0	Sn ₆ Pb	7.927	7.948	0.021	.....
69.0	31.0	Sn ₄ Pb	8.188	8.203	0.015	.....
52.7	47.3	Sn ₂ Pb	8.779	8.781	0.002	.....
35.8	64.2	SnPb	9.460	9.474	0.014	.....
21.8	78.2	SnPb ₂	10.080	10.136	0.056	.....
12.2	87.8	SnPb ₄	10.590	10.645	0.055	.....
8.5	91.5	SnPb ₆	10.815	10.857	0.042	.....
.....	100.0	Pb	11.376	.....	.....	.....

The Bi-Pb alloys show contraction, increasing regularly from both ends of the series, and reaching the maximum in the alloy with 50 parts bismuth and 50 parts lead. Similar results were obtained by Riche. The contraction is considerable, and exceeds that of nearly all other alloys.

Tin-mercury alloys (tin amalgams).—Holzmann found the results shown in table 14.

TABLE 13.—Composition and specific gravity of certain bismuth-lead alloys

Composition of alloys			Specific gravity			
Bismuth	Lead	Atomic formula	Found	Calculated	Difference	
					Expansion	Contraction
100.0	.....	Bi	9.823	.....	.....	.....
95.2	4.8	Bi ₂₀ Pb	9.893	9.887	.....	0.006
93.5	6.5	Bi ₁₆ Pb	9.934	9.902	.....	0.032
88.8	11.2	Bi ₈ Pb	10.048	9.974	.....	0.074
80.0	20.0	Bi ₄ Pb	10.235	10.048	.....	0.137
66.6	33.4	Bi ₂ Pb	10.538	10.290	.....	0.248
50.0	50.0	BiPb	10.956	10.541	.....	0.415
33.4	66.6	BiPb ₂	11.141	10.805	.....	0.336
25.0	75.0	BiPb ₃	11.161	10.942	.....	0.219
20.0	80.0	BiPb ₄	11.188	11.026	.....	0.162
16.7	83.3	BiPb ₅	11.196	11.083	.....	0.113
7.7	92.3	BiPb ₁₂	11.280	11.238	.....	0.042
—	100.0	Bi	11.376	.....	.....	.....

TABLE 14.—Composition and specific gravity of certain tin-mercury alloys

Composition of alloys			Specific gravity			
Tin	Mercury	Atomic formula	Found	Calculated	Difference	
					Expansion	Contraction
100.0	.....	Sn	7.294	.....	.....	.....
53.7	46.3	Sn ₂ Hg	9.362	9.282	.....	0.080
36.7	63.3	SnHg	10.369	10.313	.....	0.056
22.5	77.5	SnHg ₂	11.456	11.373	.....	0.083
.....	100.0	Hg	13.573	.....	.....	.....

These alloys show perceptible and approximately equal contraction. The same results were obtained by Calvert and Johnson.

Lead-mercury alloys (lead amalgams).—According to Matthiessen, the specific gravity of these alloys is shown in table 15.

TABLE 15.—Composition and specific gravity of certain lead-mercury alloys

Composition of alloys			Specific gravity			
Lead	Mercury	Atomic formula	Found	Calculated	Difference	
					Expansion	Contraction
100.0	.....	Pb	11.376			
67.4	32.6	Pb ₂ Hg	11.979	12.008	0.029	
50.8	49.2	PbHg	12.484	12.358	.....	0.126
34.1	65.9	PbHg ₂	12.815	12.734	.....	0.081
.....	100.0	Hg	13.573			

No definite regularity in the behavior of the metals can be recognized. While some metals (bismuth, gold, tin, etc.), produce chiefly contraction, and others (lead, antimony, etc.), produce expansion, there are still others (such as copper, tin, cadmium, etc.), which appear irregularly in all the groups, and there can be no doubt that certain chemical processes or actions of the separate metals upon one another play a rôle in this respect. If, for instance, a metal is capable of dissolving its own oxides (copper dissolves cuprous oxide, etc.) and decreasing thereby its specific gravity, and it is alloyed with another metal which acts in a reducing manner upon the dissolved oxide, without that the newly formed product of oxidation is dissolved, contraction will evidently take place. But, if on the contrary, a metal—silver for instance—possesses while in a liquid state the power of dissolving oxygen, which is liberated from the pure metal during the process of solidifying, and this metal is alloyed with another metal which is oxidized by the dissolved oxygen and whose product of oxidation is dissolved by the metal bath (copper), the specific gravity will evidently be decreased in consequence of this solution of oxides, and expansion take place.

From such or similar processes many apparent contradictions or irregularities in the series of specific gravities might also be deduced.

CRYSTALLIZATION

It has previously been mentioned that various alloys show a decided tendency towards crystallization, which, however, does not furnish a proof—as has frequently been supposed—of the presence of chemical combinations of the metals with each other.

If the alloy consists of metals that crystallize in the same system, the crystals of the alloy also belong, as a rule, to this system; otherwise the alloy generally crystallizes in one of the systems of the separate metals.

Copper-tin alloys usually crystallize in the hexagonal system. In an alloy of 19 parts copper and 81 parts tin, Rammelsberg found regular hexagonal prisms. From alloys richer in copper (bronzes), crystals several centimeters in length may, according to Künzel, be obtained by allowing an iron plate to float upon the liquid metal-bath not heated too much above the fusing point. The crystals deposit on the plate with their principal axes at a right angle towards the cooling surface of the plate, and can be lifted together with the latter from the liquid metal.

Nearly all copper-zinc alloys crystallize in octahedrons of the monometric system, and octahedral formations of considerable size are not infrequently found in the hollow spaces of castings, the composition of which by no means always shows a chemical combination composed according to atomic proportions. On the other hand, an alloy that corresponds to the chemical formula ZnCu (50.7 parts zinc and 49.3 parts copper) shows a peculiar long-fibrous texture, and according to Calvert and Johnson, crystallizes in prisms frequently over 1 inch in length.

Antimony-zinc alloys in all proportions of from 20 to 70% zinc yield beautifully developed crystals of the rhombic system; those richer in zinc being generally prisms, and those poorer in zinc, octahedrons.

Gold-silver, lead-silver, and silver-mercury alloys crystallize in the monometric system.

Gold-tin alloys with between 27 and 43% gold; and moreover, in all possible proportions by weight, crystallize in the dimetric system.

Iron-tin alloys crystalize in the dimetric system. Such an alloy containing about 80.5% tin and 19.5% iron remains behind, according to Rammelsberg, in quadrangular prisms, if Banka tin is dissolved in hydrochloric acid.

Iron-manganese alloys, which, as a rule, contain in addition 5 to 7% carbon, frequently crystallize in finely developed rhombic prisms. The largest and most perfect crystals are found in alloys with 30 to 60% manganese, though alloys richer in manganese also show distinct formations of crystals, while in alloys with less than 25% manganese the independent crystals are smaller and of more rare occurrence.

For foundry work the crystallization of alloys is of importance only in so far as the development of crystals generally goes hand in hand with a deterioration in the properties—that is, decrease in strength, ductility, etc.—and besides, crystallization is, as a rule, closely related to liquation. But the more slowly a casting is cooled the more opportunity the metal has to follow its inclination towards crystallization or liquation, hence it may be laid down as a general rule that crystallization should be rendered difficult by rapid cooling of the castings.

STRENGTH

The tensile strength is most frequently determined, the other kinds of strength, such as compressive strength, etc., as a rule, though not always increasing and decreasing with the tensile strength, the latter being implied here, when speaking of strength except when otherwise stated.

Like the strength of a pure metal, that of an alloy also depends to a considerable extent upon the manipulation to which it has previously been subjected. The strength of many metals and alloys can be more than doubled by mechanical manipulation—hammering, rolling, drawing—in the cold state, and this has to be taken into account in comparing the

strength of alloyed and unalloyed metals. It would be an error to compare the strength of a cast metal with that of a wire or a wrought bar of an alloy prepared from that metal. The shape and size of the cross-section have also to be taken into consideration; generally speaking, the strength is the greater the smaller the cross-section.

Regarding the influences exerted upon the strength of metals by alloying, the following general law may be laid down:

By the absorption of a foreign body the strength of metals is increased. It grows with the content of the foreign body until the latter has reached a certain proportion which varies in individual cases. When this limit has been passed the strength again decreases, frequently with great rapidity, provided the foreign body itself does not possess greater strength than the metal.

The amount of the foreign body at which the above-mentioned turning point appears varies very much. With some it lies below one per cent of the weight of the alloy; while with others the strength of the alloy only reaches its maximum when the quantity of the foreign body amounts to nearly that of the actual metal.

Metals or non-metals, which themselves possess but little strength, may also to a considerable degree increase the strength of a metal with which they are alloyed in definite proportions. Examples of this are numerous.

According to Prof. Robert H. Thurston, the strength of copper may be considerably increased by the addition of tin, though the latter alone possesses but little strength. The increase in the tensile and absolute strength appears to attain its maximum with about 17.5% tin; while with further enrichment of tin it rapidly decreases, and finally approaches gradually, though not with entire uniformity, that of tin. The crushing strength, however, reaches its maximum only with 30% tin. The brittleness of the alloy increases in all cases with the amount of tin, and only when the latter considerably exceeds 50% is there, in this respect, a gradual

approach to the properties of pure tin. Since, however, with over 20% of tin the strength rapidly decreases, and brittleness increases in a still greater degree, it is evident that where great strength is a requisite, alloys richer in tin are worthless. The torsional strength of copper-tin alloys is also greatest with 17.5% of tin, it decreasing rapidly with a higher percentage.

Small additions of zinc also increase the strength of copper, though in the cast state its tensile strength is not much more than 2 kg. per sq. mm.,* and in a rolled state scarcely more than 15 kg.

The increase in strength which can be brought about by alloying is very plainly shown with gold and silver. The usual addition to these metals consists of copper. While according to Karmarsch, hard-drawn wire of pure gold possesses an average strength of 26 kg. per sq. mm., and that of copper 39 kg., gold wire with 10% of copper shows a strength of 45.8 kg. Pure hard-drawn silver wire possesses an average strength of 36 kg. per sq. mm., while an alloy of 75 parts silver with 25 parts copper shows an average strength of 77 kg.

By the addition of a third metal to an alloy consisting of two metals it is sometimes possible to bring about an additional increase in strength. This may be shown by various examples. Copper-zinc alloys in themselves possess, as previously mentioned, less strength than copper-tin or copper-aluminum alloys, but their strength may be remarkably increased by the addition of small quantities of tin, iron, or aluminum. Thus Thurston found the tensile strength of a cast alloy of 55 parts copper, 43 parts zinc, and 2 parts tin equal to 45.7 kg. per sq. mm. The so-called "Delta" metal, which is at present much used and will be referred to later on, contains essentially 55 to 60 parts copper, 43 to 39 parts zinc, together with 1 to 1.5 parts iron. It is said to possess a tensile strength of 35 kg. per sq. mm., while a pure zinc-

* 1 kg. per sq. mm. = 1422 lb. per sq. in.

copper alloy shows scarcely more than a strength of 25 kg. By the addition of 1 part aluminum to a cast alloy of 57 parts copper and 42 parts zinc, the strength of the latter can be increased to more than 40 kg. per sq. mm., and by adding 4% of aluminum, to more than 60 kg.

The strength of gold wires alloyed with copper is also still further increased by the addition of a certain quantity of silver as a third metal. According to Karmarsch, hard-drawn wire of 58.3 parts gold, 29.7 parts copper, and 12 parts silver, possesses an average strength of 102 kg. per sq. mm.

The tenacity, as contrasted with brittleness, is more frequently measured by the change in form of the test-piece previous to breaking when tested for strength.

HARDNESS.

Hardness is really a form of strength. It is the property inherent in any material of resisting the penetration of other materials, also of compressive stresses that would tend to crush, distort, and change its shape permanently. The hardness of a mineral is often measured by its power of scratching other minerals, and this property is frequently a valuable index to the identity of the substance experimented with. In the case of metals and alloys, different forms of hardness are recognized and include, resistance to crushing strains, resistance to abrasion, resistance to the action of cutting tools, resistance to impact and resistance to penetration and possibly many other varieties of hardness could be mentioned. The two most important tests for measuring the hardness of metals are the Brinell test and the scleroscope test. The former is applied by exerting pressure on a very hard steel ball by means of a special machine, to sink it into the surface of the metal to be tested, and the depth of the impression made by the ball is measured, and forms the basis for calculating the degree of hardness of the metal tested. The scleroscope test is applied by a small machine known as the scleroscope, which is stood upon the polished surface of

the metal to be tested, and affords a means of measuring its degree of hardness by the height of the rebound of a small hard body known as the hammer, which is dropped from a standard height upon the metal under test.

By alloying metals, the hardness is usually increased, and may be greater than that of the metals constituting the alloy. Two comparatively soft metals frequently yield an alloy of considerably greater hardness than is possessed by each constituent, copper and tin, for example. In machining metals, this increase in hardness and consequent power of resisting mechanical wear is frequently the only reason for alloying them with other metals. This increase in hardness is prominently shown in various copper alloys, and is produced chiefly by tin, which, in a pure state, is comparatively soft.

Copper-tin alloys plainly show this influence. Pure copper is harder than pure tin; nevertheless 5 parts of tin in 95 parts of copper renders the alloy almost twice as hard as pure copper. With a further increase in tin, the hardness also increases considerably until the alloy contains about 20 parts of tin and 80 parts of copper. With a further increase in the tin content, the hardness at first remains approximately unchanged, or at least cannot be measured by reason of the great brittleness of the alloys. This high degree of hardness decreases only when the content of tin amounts to more than 65%.

According to an observation first made by d'Arcet, which has later on been frequently confirmed and utilized for technical purposes, the hardness of copper-tin alloys with 18 to 22% tin decreases by heating to a red heat and cooling or tempering them in water. Alloys poorer in tin, however, are not sensibly affected by this treatment.

By an addition of iron or manganese the hardness of copper, as well as of copper-tin alloys, is increased.

Of less importance is the hardening copper experiences by the absorption of zinc. The highest degree of hardness is shown by an alloy of equal parts of copper and zinc, it being about twice that of pure copper. By the addition of

zinc to copper-tin alloys, the hardness of the latter may be even somewhat reduced.

Gold and silver are made considerably harder by the addition of copper, but the amount of the latter with which the highest degree of hardness is attained, has, however, not been definitely determined. Karmarsch found that the wear of copper-silver alloys by abrasion in use, which probably is in the inverse ratio to hardness, takes place according to the following proportional figures:

Silver, %	Copper, %	Abrasion	Silver, %	Copper, %	Abrasion
99.3	0.7	2.97	52.0	48.0	1.20
90.0	10.0	1.60	31.2	68.8	1.00
75.0	25.0	1.48	21.8	78.2	1.045
65.6	34.4	1.31	.....	100.0	1.60

Hence, an alloy with 31.2% silver would be the hardest, and the hardness decreases with an increasing content of silver, as well as of copper.

The hardness of lead is considerably increased by alloying with antimony. According to investigations by Calvert and Johnson, a lead-antimony alloy with 12% antimony is about four times as hard as pure lead, and one with 23% antimony is about five times as hard. Although by a further increase in the antimony the hardness may be raised even to 12 times that of pure lead, such alloys find no technical application on account of their high degree of brittleness.

Lead-tin alloys are harder than pure lead, and when the tin content exceeds 60% are also harder than pure tin. An alloy of 70 parts tin and 30 parts lead is about $1\frac{1}{2}$ times as hard as pure lead.

Zinc-tin alloys are, according to Calvert and Johnson, harder than tin, but none of them attains the degree of hardness of zinc. The hardness increases uniformly with the zinc content.

The hardness of iron is increased by carbon (steel). A very high degree of hardness, much exceeding that attainable

by carbon alone, is imparted to iron by the addition of chromium, tungsten, molybdenum, vanadium, titanium, and nickel. Such alloys are chiefly used as tool steel. Although but relatively small quantities—0.5 to 5%, seldom more—of these metals are added, their high price makes these alloys rather expensive, so that their use is restricted to certain purposes.

FLEXIBILITY

Flexibility, in a somewhat narrower sense also called "ductility," is the capacity of certain bodies, especially metals, of undergoing while in a unfused state—permanent changes in form by the effect of mechanical forces (pull, pressure, etc.). It is closely allied to the above-mentioned tenacity in so far as it is measured by the permanent change in form taking place before fracture. For flexibility, a certain degree of tenacity is always required, because the permanent change in form becomes possible only when the limit of elasticity has been exceeded. The more readily fractures take place thereby the less flexible the material.

In tests for strength, the tenacity, as previously mentioned, is usually measured by the change in form which the test-piece suffers previous to fracture (elongation in testing tensile strength, compression in testing compressive strength). However, in addition to the tenacity of the body, flexibility depends on various other conditions. The extent of the change in form which a material can stand without undergoing fracture has first to be taken into account, especially the smallness of the cross-section to which it can be stretched or drawn out. Gold and silver are considered the most flexible of all the metals, chiefly so because no other metal can be stretched to such thin cross-sections as shown by gold leaf and silver leaf. There has further to be considered the extent of the mechanical work which is required for giving the material a definite form, and this depends partly on the limit of elasticity of the material. The lower the limit of elasticity lies, and the less resistance the particles offer to their being shifted after pass-

ing the limit of elasticity, the less consumption of work for the change of form will be required, and the more flexible the material appears. However, the greater the strength the less danger there is of the material suffering fracture after the limit of elasticity has been passed. In this sense the difference between limit of elasticity and strength is also of importance for the degree of flexibility. The temperature at which the material is worked has also to be taken into account. Many metals possessing but little flexibility at the ordinary temperature become more flexible by heating (iron, copper), while others lose thereby on flexibility (brass, German silver).

Although, from what has been said, it is impossible to establish a scale of flexibility of the metals and alloys appropriate to all cases, observation has shown that, generally speaking, the purest metals possess the greatest flexibility, and that by alloying, this property is diminished and sometimes almost reduced to no value.

The flexibility of copper in the cold state is materially injured by a very small quantity of lead, perceptibly so with 0.25%, and still more so when heated. Copper alloys with 6% tin, have, while in a cold state, almost entirely lost their flexibility; but when heated show a moderate degree of it if their tin content is not much over 15%. On the other hand, while zinc increases the strength and hardness of copper to a far less extent than tin, its effect upon the flexibility of copper is far less, zinc-copper alloys with equal proportions by weight of both metals possessing still a certain, though low, degree of flexibility.

Gold and silver also become less flexible when alloyed with other metals, and are therefore used in a pure state when the highest degree of flexibility is demanded, for instance, in the preparation of gold leaf and silver leaf. The least injurious effect is produced by copper, though both of the metals thereby lose perceptibly in tenacity and flexibility.

A small amount of zinc appears to have a beneficial effect upon the flexibility of many gold-copper and silver-copper alloys, especially when they contain much copper. Accord-

ing to Peligot, gold-copper alloys with 58 to 60% gold, which by themselves are difficult to work, become more ductile by replacing 5 to 7% of the copper with the same quantity of zinc; thus 58 to 60% gold, 35 to 37% copper, and 5 to 7% zinc. However, if the zinc content exceeds this limit, the ductility decreases. Alloys with more than 1 to 2.5% of gold also become less ductile by small quantities of zinc.

The effect of bismuth is especially injurious to the flexibility of many metals—gold, silver, lead, tin, copper—0.05% being sufficient to render each one of these metals useless for purposes requiring a high degree of flexibility. Antimony and arsenic may also produce an injurious effect, even in small quantities. The flexibility of zinc is especially impaired by small quantities of tin, 0.1% producing a remarkable effect in this respect.

An exception to the rule according to which pure metals are more flexible than alloyed metals would seem to be found in cases where the flexibility as well as the tenacity has been impaired by the absorption of oxygen, and the separation of oxygen has been effected by the addition of another body. Thus, according to Charpy's investigations, the flexibility of copper containing oxygen can be increased by a moderate addition of zinc; similar cases have been frequently observed. However, every excess of the addition not required for the purpose more or less diminishes the flexibility instead of increasing it.

CASTING CAPACITY

The most important property of metals for the manufacture of many articles, is their ability, when in a molten state, of being cast in molds and filling completely every portion, even the smallest cross-section, of the latter. However this quality again depends on four other properties, as under:

1. *Melting temperature.*—The lower the melting temperature the more readily the material to be cast can be con-

verted into the liquid state, and the more convenient its use for casting.

By alloying, the melting temperature of metals is frequently lowered—that is, the melting temperatures of the alloys are lower than they would be according to calculation, if computed from the melting temperatures of the constituent metals and their proportions by weight. Furthermore, by the addition of a metal melting at a higher temperature to one melting at a lower one, the melting temperature of the latter is frequently lowered instead of raised. The melting temperature begins to rise again only when the amount of the more refractory metal in the alloy exceeds a certain limit at which lies the lowest melting temperature attainable, hence, when the composition of the eutectic alloy is reached. There are numerous examples of this and some typical cases are given below:

(a) Tin melts at 449.4°F. , and lead at 631.3°F. By alloying certain quantities of lead with tin, the melting temperature of the latter can be still further lowered, its lowest point being reached with an alloy of about 31 parts lead and 69 parts tin (melting temperature 356°F.). It rises again with an increase in the lead content approaching more and more that of pure lead.

It has been previously stated that the melting temperature of lead (631.3°F.), is lowered by the absorption of small quantities of silver (melting temperature, 1761°F.), the lowest melting temperature being that of an alloy with about 4% of silver. With either an increase or a decrease in the amount of silver the melting temperature is higher.

(b) Copper melts at 1981.5°F. , and silver at 1761°F. The eutectic alloy of both metals contains, as previously stated, 72 parts silver and 28 parts copper, and congeals at 1418°F.

(c) The melting temperature of pure iron is considerably lowered by the addition of various elements, especially so by carbon, which alone is infusible in ordinary furnaces. The melting temperature of iron is reduced about 212°F. , by the

absorption of 1% of carbon, and iron with 4% of carbon melts at a much lower temperature.

(d) On the other hand, there are alloys whose actual melting temperatures agree well with those obtained by calculation; or are even somewhat higher. If, in the first case, all

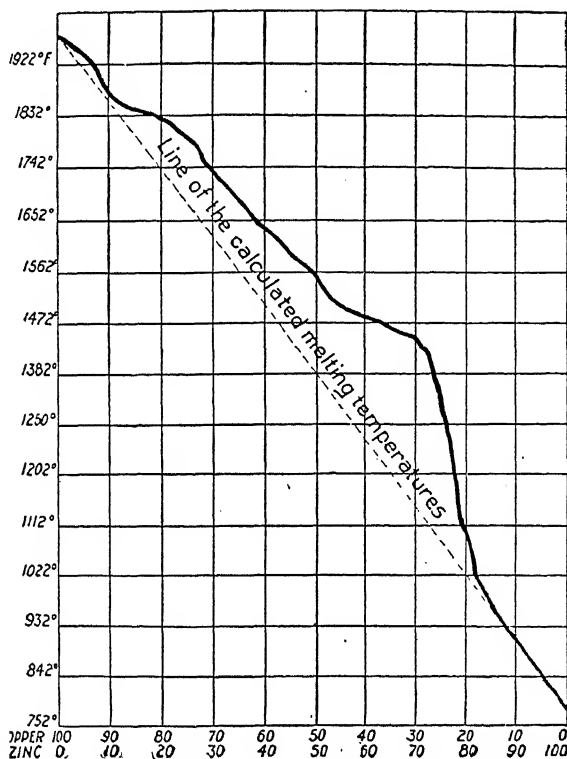


Figure 22.—Curve of melting temperatures.

the alloys of the same group behave in the same manner, the line in which the melting temperatures of the alloys converge and which connects the melting temperatures of the pure metals, is a straight one (see figure 22). To this belong, for instance, the alloys of gold and of silver, which melt at 1913° and 1761° F., respectively. In the second case the line of view of the melting temperatures lies above the straight

line drawn between the melting temperatures of the separate metals. Copper-zinc alloys may be mentioned as an example. Zinc melts at 779° F., and copper at 1981.5° F. Maurice Lucas found the following melting temperatures of alloys to which, for the sake of comparison, are added those found by calculation:

TABLE 16.—*Calculated and actual melting temperatures of copper-zinc alloys*

Copper, %	Zinc, %	Melting temperature found, ° F.	Melting temperature calculated, ° F.
90.5	9.5	1868	1868
80.3	19.7	1832	1745.6
69.5	30.5	1733	1614.3
60.2	39.8	1616	1502.6
51.0	49.0	1533.6	1391
39.7	60.3	1493.6	1256
31.0	69.0	1457	1171.6
25.1	74.9	1292	1083.2
20.4	79.6	1097.6	1023.8

Figure 22 shows the line of melting temperatures. There being no eutectic temperature from the sharp curve of the line at about 30% copper, the presence of a more intimate chemical combination, may be inferred, the composition of which would correspond to the formula Zn_2Cu (with 32.8% copper and 67.2% zinc), and which during solidification separates from the alloys richer in zinc. This alloy, as confirmed by various investigators, is distinguished from the other alloys of this group by its great brittleness, color, and chemical behavior.

By the addition of a third or fourth metal to an alloy, a further reduction in the melting temperature can be effected. Therefore, generally speaking, the greater the number of constituents of which the alloys consist the further the actual melting temperatures of the alloys lie below those found by calculation. This rule is frequently made use of in the manufacture of very fusible alloys, it being possible by combining several metals in suitable proportions by weight, to make alloys which melt in boiling water. An alloy of 8 parts lead,

3 parts tin, and 8 parts bismuth (Rose's metal) melts at 203° F.; and another of 8 parts lead, 4 parts tin, 15 parts bismuth, and 3 parts cadmium (Wood's metal), at 154.4° F.

2. *Fluidity*.—In addition to the melting temperature, the degree of fluidity of a molten metal also exerts an influence upon its casting capacity. The more thinly-fluid it is the more readily and the more completely it fills the thinnest cross-sections of the mold. To be sure its fluidity is partly dependent on the degree of overheating above the melting temperature in melting, and the lower the latter is the more readily a thinly-fluid state will be obtained. However, independent of this, there is no conformity in the behavior of the metals. Just as oil is more thickly-fluid than water even when both are to the same extent heated above their boiling points, one metal is more thickly-fluid than another. Such as gradually soften (copper, wrought iron, etc.) as a rule are also more thickly-fluid in a molten state than those which melt suddenly (bronze, cast iron). However, as a rule, alloyed metals pass less gradually into the fluid state than pure metals, and this is without doubt closely connected with the fact observed in foundry practice that alloys in general are more thinly-fluid than non-alloyed metals. On the other hand, some non-metals, especially oxygen and sulphur, render thickly-fluid many metals by which they have been absorbed. Copper and bronze containing oxygen are more thickly-fluid than when free from it, and iron containing sulphur is more thickly-fluid than when free from it.

3. *Development of gases*.—The casting capacity of a metal is materially impaired if it possesses the property of developing gases while in a fluid state. If this development of gas takes place shortly before solidification, the gases can no longer escape, and the resulting casting is full of gas bubbles. On the other hand, if the metal, previous to complete solidification, passes through a dough-like condition, it swells up under the pressure of the developing gases, scatters when solidifying with a free surface, and becomes unfit to fill any mold sharply. Since the volume of gases increases materially

with the temperature, this process is more plainly perceptible with refractory metals than with those more readily fusible.

This action, frequently observed in casting metals, may be ascribed to various causes. It may sometimes be due to gases in solution, which, shortly before the metal passes into the solid state, reassume their gaseous form. Various metals—for instance, iron and copper—dissolve hydrogen, and in melting, find abundant opportunity for absorbing it. Nitrogen may be dissolved by liquid metals; and some metals—silver, for instance—dissolve oxygen without entering into a more intimate combination with it.

Whether or not, and in what direction, the capacity of metals to dissolve gases is changed by alloying, has thus far not been definitely determined. Observations made in casting lead, however, lead to the conclusion that, as a rule, alloyed metals are less capable of dissolving gases than pure metals. The development of dissolved gases may, however, be sometimes prevented by adding to the metal a body that enters with the dissolved gas into a non-volatile combination which does not again disintegrate. Thus, for instance, the oxygen dissolved by fluid silver escapes with violence shortly before solidification, and frequently produces vigorous scattering (“sprouting”) and in every case renders the casting of pure silver a difficult process. If, however, copper be alloyed with the silver, an adequate portion of it combines with the absorbed oxygen to form cuprous oxide, which, though it remains dissolved in the metal, does not disintegrate; the development of gas is thus avoided, if not caused by other conditions. The greater the proportion of copper to silver the more complete the result will be. Zinc, possessing a stronger tendency towards combining with oxygen, acts still more vigorously than copper.

The gases, however, originate not less frequently from a chemical process in the interior of the liquid metal itself, their formation being first caused thereby. If, for instance, in addition to dissolved oxides—or under circumstances in addition to oxygen which was simply in solution—the metal

contains other substances which enter into new gaseous combinations with the oxygen present, a development of gas must be brought about by this process. This takes place very rapidly if the body combining with the oxygen has a strong affinity for the latter, and is present in great excess. It progresses, however, more gradually, and for this very reason is more detrimental to the casting capacity, when the affinity for oxygen of the second body is only slightly greater than that of the metal whose oxide was dissolved, and when it is present in the metal-bath in a greatly diluted state. Thus, for instance, commercial copper contains in addition to some cuprous oxide, some cuprous sulphide, and both of these act on one another, gaseous sulphurous acid being formed thereby. The cuprous sulphide is, however, present in the liquid metal in a greatly diluted state, and the action does not take place suddenly, but progresses very gradually, so that gas is uninterruptedly evolved from the molten copper, rendering the latter unfit for castings. By calculating the volume which definite quantities of sulphurous acid occupy in the solidifying temperature, it will be readily understood that even an apparently very small amount of sulphur is capable of producing perceptible effects. Iron, as well as nickel, always contains carbon, and if oxygen is also present in the metal, the formation of carbon monoxide is caused by their reciprocal action, which, like sulphurous acid in the above-mentioned case, may make the metal unfit for casting purposes.

The development of gas must stop, if, in such cases, the metal is alloyed with a substance, which, by reason of its stronger affinity for oxygen, attracts the latter, and the oxide of which is either separated in an insoluble state in the metal-bath; or at least is no longer disintegrated in the manner previously described. With copper, for instance, this result is attained by the addition of zinc; aluminum, phosphorus, or silicon acting still more vigorously. With nickel, an addition of zinc also answers the purpose, though magnesium is still more effective. With iron, manganese is as a rule used for the disintegration of the dissolved ferrous oxide; but

as the resulting manganous oxide is itself again affected by the carbon present, though somewhat more slowly than the ferrous oxide previously present, an entirely complete result is not attained. The object is, however, accomplished with greater certainty by aluminum; in fact, large quantities of this metal are now used for this purpose, but an excess of the added aluminum remaining in the iron makes the latter thickly-fluid, and also impairs its mechanical behavior, and must therefore be avoided.

From what has been said it is evident that by suitably alloying a metal, its capacity for developing gases while in a liquid state can be decreased or entirely overcome.

4. *Shrinkage*.—When a liquid metal congeals, it at first expands like freezing water, consequently the congealed portion floats upon the liquid metal like ice upon water. This, however, as cooling progresses, is followed by a contraction which is nearly always greater than the previous expansion. Hence the articles produced by casting are, when cold, smaller in dimension than the molds which served for the reception of the liquid metal. This process is called “shrinkage.”

In many respects the shrinkage of metals renders the production of serviceable castings more difficult, and the greater the degree of shrinkage the more this fact becomes apparent. If a casting has, in different portions, cross-sections of varying thickness which do not simultaneously congeal and shrink, a strain or even a crack may be formed in the casting; but where the metal remains liquid the longest, hence usually in the center of the casting, a hollow space is formed which may render the article entirely useless. In casting liquating alloys, accumulations of more readily fusible alloys may easily form in this hollow space.

A law according to which the degree of shrinkage of alloys could be deduced from that of the separate metals cannot be laid down. Alloys frequently shrink to a greater extent than each of their constituents. Pure copper, * for instance,

* Pure copper is not generally used for casting, and an accurate determination of its degree of shrinkage is connected with difficulties by reason of its tendency to develop gases in casting and swelling up thereby.

shrinks but little; pure tin, $\frac{1}{147}$; and pure zinc, $\frac{1}{80}$. On the other hand, a copper-tin alloy with 10% tin shrinks $\frac{1}{130}$; with 20% tin, $\frac{1}{65}$; and a copper-zinc alloy with 30% zinc, $\frac{1}{62}$. The degree of shrinkage of tin-lead alloys is small, and increases with the lead content. (The degree of shrinkage of pure lead is $\frac{1}{92}$.)

CONDUCTIVITY FOR HEAT AND ELECTRICITY

Good conductors for heat are, as a rule, also good conductors for electricity, and vice versa. Among the metals, silver is considered the best conductor for heat and electricity, followed by pure copper and gold.

Experiments, as well as observations in using metals, have shown that the purest metals are the best conductors; and on alloying, their conductivity is almost always impaired. According to Matthiessen's investigation, lead, tin, cadmium, and zinc are the only metals whose conducting power for electricity is not materially impaired when alloyed with one another, but corresponds to that found by calculation. The conducting power of these metals, however, decreases when they are alloyed with other metals.

It becomes evident also that, similar to the effect of alloying upon other properties, the conductivity of a less good conductor may be still further decreased by alloying even with a good conductor.

Taking the conductivity of silver for heat and electricity as 100, Wiedmann found the conductivity of copper for heat to be 73.6, and for electricity, 79.3; while that of zinc for heat was 28.1, and for electricity, 27.3. Also that of an alloy of 2.1 parts copper and 1 part zinc, for heat was 25.8, and for electricity, 25.4.

Very small quantities of a foreign body are frequently sufficient to effect a considerable decrease in conductivity. According to Matthiessen and Holtzmann, the electrical conductivity of pure copper is diminished 27% by the absorption of only 0.13% of lead; 40% by 3.2% of zinc; 14% by

2.45% of silver; 80% by 4.90% of tin; 86% by 2.80% of arsenic; and 92% by 2.50% of phosphorus.

Hampe found that the conductivity of copper may be diminished 50% by 0.35% of arsenic, and about 25% by 0.5% of silicon.

In such cases, previously referred to, where a metal contains its own oxide in solution, the latter may, like another alloyed body, impair the conductivity. Matthiessen and Holtzmann further found that copper, which had become oxidized by melting in air, conducted electricity only in the proportion of 63.37 to 93.00, as compared with copper whose content of oxygen had been destroyed by the action of hydrogen gas. The conductivity might possibly be increased by removing the oxygen from such a metal in the manner previously referred to—that is, by the addition of a body which by reason of its greater affinity for oxygen combines with the latter, and the oxide of which is insoluble in the metal-bath. However, without an excess of such an addition, a complete separation of the oxygen is scarcely possible, and there is then danger of this excess exerting just as an injurious, or still more injurious, effect than the oxygen originally present. An addition of phosphorus to copper for the purpose of increasing the conductivity by destroying the cuprous oxide present would, for instance, be scarcely a success, since, as shown by the figures given above, a very small quantity of phosphorus in excess greatly diminishes the conductivity. As shown by Hampe's investigations, an addition of silicon, which has recently been frequently used in the manufacture of conducting wires, also considerably impairs the conductivity; and the actual object of such an addition is very likely that of increasing the strength of the wire. The problem of finding a suitable addition which will not impair the conductivity has thus far not been solved.

COLOR OF ALLOYS

Regarding the color of alloys, it may also be said that the intensity of the effect produced by the addition of deter-

mined quantities of one metal to another is not equally strong throughout, but shows considerable variations; the color of an alloy does not always form the compound color from the colors of the alloyed metals, but frequently exhibits independent tones. While, for instance, in copper-silver alloys the color of the one metal passes fairly regularly into that of the other, and hence forms an actual compound color, in some copper-tin alloys—and still more so in some copper-zinc alloys with a comparatively high content of copper—the red color disappears almost completely, being replaced by a yellow shade which cannot be produced by simply mixing red and white, or red and gray.

The diversity in color of the metals used for technical purposes is not very great, copper, for instance, being red and gold, yellow; the others are either white or pale gray, in the various shades of the pure white of silver and tin to the pale gray of lead, platinum, etc. Two or more white metals alloyed with one another always give white alloys.

White metals alloyed with red copper give reddish-white, reddish-yellow, pure yellow, gray, or white alloys. White metals alloyed with gold give pale yellow, greenish, or white alloys.

As previously mentioned, the intensity of coloration produced in an alloy by the addition of one or another metal varies considerably. For the metals more frequently used for colored alloys, the following scale may be adopted:

Tin, nickel, aluminum,	Lead,
Manganese,	Platinum,
Iron,	Silver,
Copper,	Gold.
Zinc,	

Each metal in this series standing before another exerts a stronger influence upon the color than the succeeding one, so that the color of the latter frequently disappears by the addition of comparatively small quantities of the former. However, the different shades of color do not appear gradually

and uniformly with the increase or decrease in the content of the one metal, sudden transitions being frequently observed; and it may even happen that an alloy with a larger quantity of a white coloring metal may show a darker tone of color than the same alloy with a smaller quantity of the same metal.

The varying intensity of coloration produced by copper, tin, and zinc, may be very plainly recognized by a comparison of the scale of color of copper-tin and copper-zinc alloys:

TABLE 17.—*Comparison of color-scale of copper-tin, copper-zinc, and copper-tin-zinc alloys*

Copper, %	Copper-tin alloys		Copper-zinc alloys		Copper-tin-zinc alloys		
	Tin, %	Color	Zinc, %	Color	Tin, %	Zinc, %	Color
95	5	Red-yellow, gold-like	5	Red, almost copper color			
90	10	Reddish-gold-yellow	10	Yellow, red-brownish			
84	16	Reddish-gold	16	Red-yellow	5	11	Orange-red
80	20	Reddish-gray	20	Reddish-yellow	4	16	Orange-yellow
78	22	Yellow-gray	22	Reddish-yellow	4	18	Orange-yellow
75	25	Reddish-white	25	Pale yellow			
73	27	Reddish-white	27	Yellow	4	23	Pale orange
70	30	White	30	Yellow	3	27	Pale yellow
65	35	Bluish-white	35	Deep yellow	3	32	Light yellow
62	38	Bluish-gray	38	Deep yellow			
59	41	Gray	41	Reddish-yellow			
50	50	Pale gray	50	Handsome gold-yellow			
40	60	Gray-white	60	Bismuth gray, with strong luster			
30	70	Gray-white	70	Antimony gray			
20	80	Whitish	80	Zinc gray			
10	90	Whitish	90	Zinc gray			

From the above table it will be seen that while the color of copper, vivid by itself, is almost completely covered by a 30% tin content, it is converted by the same quantity of zinc first into yellow, and about 60% of zinc is required to make it entirely disappear. The fact that in copper-zinc alloys with 25 to about 35% of zinc the color appears pure yellow (brass-yellow) and with a still higher zinc content (up to 50%), golden yellow, is also of interest and considerable practical importance. Still warmer tones of color are obtained, as shown in the third column of the table, by replacing in the alloys richer in copper (70 to 80% copper) a portion of the zinc by tin.

The great coloring power of nickel is best shown in nickel coins, which contain 75% copper and 25% nickel. Notwithstanding the large amount of copper, the color of the latter has entirely disappeared.

Gold possesses but slight coloring power. Gold-silver alloys with 64% gold show a greenish-yellow color, and with 30% gold a perfectly white color like fine silver. When gold is alloyed with copper, the gold color disappears completely with about 75% of copper, the alloys exhibiting the red color of rosette copper, while in a silver-copper alloy, with the same quantity of copper, the silver content can be plainly recognized.

RESISTANCE TO CHEMICAL INFLUENCES

A knowledge of the resistance of alloys to chemical influences is of considerable practical importance. Nearly all articles of metal and alloys are exposed to the action of gases contained in the atmosphere (besides the quite indifferent gas nitrogen, there are oxygen, carbonic acid, and aqueous vapor; and in inhabited localities nearly always sulphuretted hydrogen, ammonia, etc.), and many of them to that of rain and snow; while utensils for culinary and technical purposes are also affected by acid, alkaline, saline, or fatty fluids. For the manufacture of such utensils it might be desirable, as regards other properties, to alloy the metal to be used for the purpose with another, but the question is whether such an alloy possesses the same power of resisting chemical influences as the pure metal. Thus, for instance, tin containing lead is preferable in many respects to pure tin, it being harder, stronger, and filling the molds better in casting; but if the alloy is to be used for kitchen utensils, drinking vessels, or similar purposes, the important question arises whether, in view of the poisonous properties of lead it is capable of resisting in the same degree as pure tin the chemical influences to which it may be exposed.

Few experiments have been made to determine the behavior of alloys in this respect, but it is generally found that

the action of the atmosphere is less severe on alloys than on their component metals. An instance of this are the ancient bronze statues and coins, some of the latter having their characters still legible, although they have been exposed to the effects of air and moisture for upwards of twenty centuries.

Oxidation.—The action of the atmosphere on an alloy heated to a high temperature is sometimes quite energetic, as is shown in the alloy of 3 parts lead and 1 part tin, which, when heated to redness, burns briskly to a red oxide. When two metals—copper and tin, for instance—which oxidize at different temperatures, are combined, they may be separated by continued fusion with exposure to the air. Cupellation of the precious metals is a similar action. In this process, a few grams of lead—as in an assay cupel—or several hundred pounds of lead—as in a refinery—part of the lead is absorbed by the cupel, but most is oxidized to litharge (PbO), and the silver and gold remain as a bead or lump in the bottom of the cupel.

By alloying one metal with another, the chemical action of a body upon the alloy is frequently reduced to a less degree than would correspond to the simple dilution of the metal; and two metals, which in a pure state are very sensitive to chemical influences, may even show a comparatively great power of resisting these influences when alloyed in definite proportions with one another. However, two alloys composed of the same metals, but in different proportions, may, in this respect, exhibit considerable variations; and it may happen that an alloy with a larger amount of a metal possessing but slight power of resisting certain influences, may be less attacked by the same agents than another alloy with a smaller content of the same metal.

Some investigators have considered this peculiarity of some alloys an indication of the presence of actual chemical combinations. However, a contrary behavior has also been frequently observed. Thus, St. Claire Deville found that a lead-platinum alloy was entirely decomposed by the action of

the air, the lead being converted into lead carbonate (white lead), while a piece of pure lead lying alongside of it remained unchanged. Among the silver-copper alloys, that containing 25% of copper tarnishes to a greater degree in air containing sulphuretted hydrogen than pure silver, etc.

Calvert and Johnson have investigated the resistance of different copper-tin and copper-zinc alloys to acids and salts, and made the remarkable observation that nitric acid of 1.14 specific gravity dissolves the two metals in an alloy of zinc and copper in the exact proportion in which they exist in the alloy employed; while an acid of 1.08 sp. gr. dissolved nearly the whole of the zinc and only a small quantity of the copper. Hydrochloric acid of 1.05 sp. gr., which readily dissolves zinc, was found to be completely inactive on all alloys of copper and zinc containing an excess of copper, and especially on the alloy containing equivalent proportions of each metal. Zinc was found to have an extraordinary preventive influence on the action of strong sulphuric acid on copper. The alloy Cu_4Zn_3 (56.5% copper) was but little attacked by concentrated hydrochloric or nitric acid, and not at all by sulphuric acid.

Copper-tin alloys were found to resist the action of nitric acid more than pure copper, but the preventive influence of tin presents the peculiarity that the action of the acid increases as the proportion of tin increases. Thus the alloy CuSn_5 is attacked ten times more than the alloy CuSn .

Among the copper-tin-zinc alloys the two alloys, $\text{Cu}_{18}\text{SnZn}$ (86% copper, 9% tin, 5% zinc), and $\text{Cu}_{10}\text{SnZn}$ (77% copper, 14.5% tin, 8% zinc), were found to be only slightly attacked by strong nitric or hydrochloric acid, hence, they behaved similarly to the above-mentioned alloy Cu_4Zn_3 . The resistance of these alloys against the action of nitric acid deserves special attention, since the acid readily attacks each of the separate metals.

Regarding the influence of sea water upon copper-zinc and copper-zinc-tin alloys, Calvert and Johnson found that from pure copper-zinc alloys, zinc is chiefly dissolved, the

copper being therefore protected by an addition of zinc; and that in the ternary alloys of the mentioned metals, the solution of zinc is smaller and that of copper considerably larger than in copper-zinc alloys. Hence, by the addition of tin, the zinc is protected and the copper more exposed; though with an equivalent proportion of copper a reduction in the total effect could not be recognized. On the other hand, the action of sea water is weakened by a small addition of lead and iron to copper-zinc alloys (see Muntz metal).

Articles of copper-tin alloys richer in copper, when exposed for a long time to the action of the air, acquire a beautiful pale green or brownish crust called *patina*, consisting mostly of the hydroxides and carbonates of the component metals. This is highly esteemed, partly on account of the beautiful appearance it presents, and partly as a characteristic of antique articles; and artisans have sought to promote its formation partly by a suitable choice of the alloy and partly by the use of chemical agents. On an alloy consisting of 89.78% Cu, 6.83% Sn, 1.85% Pb, 0.90% Co and Ni, and 0.28% Fe, J. Schuler found a patina of the following composition:

<i>Analysis of patina</i>	Per cent
SnO ₂	49.13
CuO.....	22.46
PbO.....	3.53
Fe ₂ O ₃ .Al ₂ O ₃	1.75
CO ₂	6.35
H ₂ O.....	8.48
Organic substance.....	0.76
H.....	0.65
Insoluble matter.....	6.16

Or, omitting the accidental foreign substances (organic substances, sand, etc.):

SnO ₃ H ₂	60.92
CuCO ₃ .CuO ₂ H ₂	34.55
(PbCO ₃) ₂ PbO ₂ H ₂	4.51

It is remarkable, that in this patina the proportion of copper to the other metals is much smaller than in the bronze.

In copper-silver alloys the copper may protect the silver

from the attack of single agents; but the silver, even when present in excess, does not protect the copper. Thus copper is dissolved by acetic acid from alloys with 80% and upward of silver, a fact which deserves attention in using household utensils of silver alloyed with copper. By boiling copper-silver alloys with dilute sulphuric acid, the greater portion of the copper is dissolved, while nearly all the silver remains behind. It has previously been mentioned that the action of sulphuretted hydrogen is more pronounced upon silver alloyed with copper than upon pure silver, the article first becoming covered with a yellowish and then a brownish coat, which finally turns blue.

In gold-silver alloys the gold, if present in excess, may weaken or entirely overcome the action of certain acids on silver. While from alloys poor in gold all the silver may be extracted by sulphuric acid, an alloy containing more than 50% gold is not affected.

The action of acids and salt solutions on lead-tin alloys has been more thoroughly investigated on account of the poisonous properties of lead, vessels of tin containing lead being much used for household and commercial purposes. Pleischl, Roussin, Reichelt, and others have shown that acetic acid and a solution of common salt, or a mixture of both, dissolve lead from lead-tin alloys even if they contain only 2% of lead, the quantity of lead dissolved increasing, of course, with the lead content in the alloy, and depending on the time of action.

Knapp investigated lead-tin alloys, preparing three alloys of different composition, namely, (*a*) 30.8 parts tin and 69.2 parts lead; (*b*) 21 parts tin and 79 parts lead (corresponding to the formula SnPb_2); (*c*) 80 parts tin and 20 parts lead.

Toward distilled water, with access of air, the alloy *a* showed the greatest resistance, while from *a* and *b* a comparatively large quantity of oxide of lead (consisting of lead, carbonic acid, and water) was separated.

During a period of 7 days, cold vinegar dissolved the amounts shown below from $15\frac{1}{2}$ sq. in. surface:

	Lead, gram	Tin, gram	Total, gram
From alloy <i>a</i>	0.0677	0.0267	0.0944
From alloy <i>b</i>	0.0773	0.0159	0.0932
From alloy <i>c</i>	0.0027	0.0337	0.0364

Hence, the alloy richest in tin showed the greatest resistance towards the action of cold vinegar, while the alloy *a* proved no more resistant than the alloy with 79 parts lead; while for the same quantity of tin, the alloy *a* contains about 9 times as much lead as *c*, it yields to vinegar 26 times as much lead.

Boiling vinegar dissolved the following in the course of one hour:

	Lead, gram	Tin, gram	Total, gram
From alloy <i>a</i>	0.0130	0.0032	0.0162
From alloy <i>b</i>	0.0118	0.0055	0.0173
From alloy <i>c</i>	0.0058	0.0100	0.0158

The difference in the resistant power of the alloy richer in tin as compared with the two others, is, therefore, considerably diminished by boiling, and, by taking into consideration the total quantity of metal dissolved, the *a* alloy proves nearly as resistant as the alloy richer in tin, the amount of lead dissolved being, however, nearly double. By taking into consideration the short period of action, it will be seen that the effect of the acid is considerably increased by the higher temperature.

A cold solution of common salt (3.5% sodium chloride), only dissolved lead in the course of 7 days from all three alloys, and no tin. The amount of lead dissolved per 15½ sq. in. of surface was:

	Gram
From alloy <i>a</i>	0.0023
From alloy <i>b</i>	Trace
From alloy <i>c</i>	0.0499

In this case the alloy poorest in lead loses the greatest quantity of that metal.

At a boiling heat, the same salt solution in the course of

one hour also dissolved tin, the amount per $15\frac{1}{2}$ sq. in. surface being:

	Lead, gram	Tin, gram	Total, gram
From alloy <i>a</i>	0.0078	0.0022	0.0100
From alloy <i>b</i>	0.0080	0.0012	0.0092
From alloy <i>c</i>	0.0036	0.0020	0.0056

In this case the alloy richest in tin suffers the smallest total loss in metal; but in proportion to its content of lead, a comparatively large amount of the latter is dissolved.

The results of these experiments show the extent to which the resisting power of one and the same alloy is dependent upon the nature of the influences to which it is exposed, and the temperature at which they act.

R. Weber made a number of experiments with lead-tin alloys in regard to their behavior towards vinegar, and his investigations show that generally speaking, the alloys are the more strongly attacked the greater their lead content, no exception from this rule for some alloys richer in lead having been found. Further, antimony does not prevent the alloy from being attacked; and when vinegar is mixed with one-quarter its volume of tartaric acid, the quantity of metal dissolved is increased four-fold.

In Germany, by law, vessels intended for measuring fluids must not contain more than 1 part lead to 5 parts tin.

CHAPTER V

THE ART OF ALLOYING: MELTING AND COMBINATIONS

IN general, alloys are made first by melting the metal forming the bulk of the alloy, and then adding the more fusible metals in a solid state. This is the method practiced in the case of most alloys of copper. On account of its higher melting point, the copper is first melted; then the other metals—tin, lead, zinc, or aluminum—are added to the molten copper, and as their melting points are low compared with the copper, they quickly melt and go into solution.

CRUCIBLES

The more refractory alloys are melted in graphite crucibles (figure 23), or in bulk in closed furnaces capable of reaching a high temperature. The more easily fusible metals, such as tin and lead, are melted in kettles, usually made of iron. Crucibles are made of graphite or plumbago and clay with a small amount of sand. The plumbago adds to the refractoriness of the mixture of earths, and also confers the quality of heat conductivity. Sometimes all-clay crucibles are used, though much less so than formerly. The clay crucible has a short life because it has to be made thin to enable the heat to penetrate and reach the metal within. Being fragile, the crucibles are very subject to breakage, and although cheaper at first, by reason of their short life cost in the end more than graphite crucibles, so that the latter have almost entirely supplanted them. Clay crucibles are very convenient for fire assays, when ores are reduced with fluxes to determine their metal content. In such operations, the melt is either poured into molds or allowed to solidify in the crucible. If the

latter method is practiced, the crucible is broken to obtain the metal, and the crucible of course, is used for only one heat;



Figure 23.—Standard graphite crucibles and retorts (Dixon).

but if the melt is poured, a good grade of crucible should last at least six heats.

Crucibles are heated in furnaces, the heating medium be-

ing gas, oil, distillates, coke, hard coal, or electricity. They may be taken from the furnace by means of tongs and emptied by tilting; or the crucibles may be fixed in the furnace, and to empty it, the entire furnace is tilted over by some mechanical appliance forming a part of the furnace. The capacity of crucibles in both types of furnaces will vary according to the character of the castings being made. In the case of small or very thin castings, a convenient size of crucible is No. 35 or 40, the latter being mostly favored. Assuming 3 lb. of liquid metal to the crucible number, the No. 35 will contain 105 lb. of metal, and the No. 40, 120 lb. As the capacity of the crucibles shrinks with use, and as it is desirable to calculate the heats in hundreds, or multiples of hundreds, the No. 35 would not contain 100 lb. throughout its life without danger of overflowing into the furnace; therefore the No. 40 size is preferable, as it can be depended upon to contain the heat of metal even after the top has worn down. (Another method for determining the capacity of crucibles is to multiply the number of liquid pints by the specific gravity of the metal to be melted.)

For making heavy castings, larger crucibles are used in both "pull-out" and tilting furnaces. A common size of crucible for pull-out furnaces is the No. 100, holding 300 lb. of molten metal. But even larger ones are used than this size in pull-out furnaces. In tilting furnaces, the capacity may be as high as 1500 lb., but more commonly from 375 to 600 lb., a favorite size being the No. 150, holding 450 lb. of metal.

For the preparation of alloys from precious or rare metals, it is best to effect the fusion in crucibles of graphite or of graphite mixed with clay, as the metal readily and completely separates from such crucibles. And regarding graphite crucibles we would draw attention to one of their peculiarities, namely, that of bursting. It sometimes happens that a short time after being placed in the furnace a graphite crucible bursts with a loud report, and the metals contained therein fall into the fire, from which they have to be rescued



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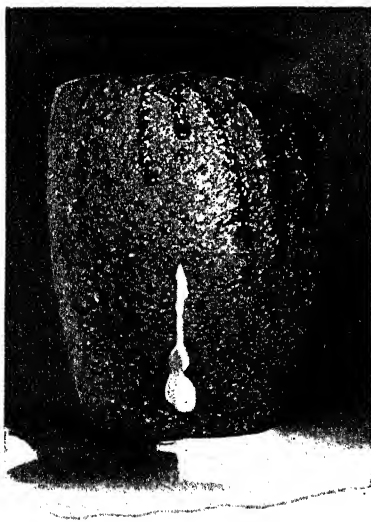


Figure 24.—A. Scalped crucible (Dixon). B. Alligator cracks. C. Pinhole or leak (Bartley).

with considerable trouble. In figure 24 is shown a burst, or "scalped" crucible, as they are termed.

This phenomenon is seldom due to faulty work in making the crucible, but to the presence of moisture within its walls. This moisture may have been absorbed during transit, or during the period of storage. It is rarely that the crucible bursts into pieces so that the contents are spilled in the furnace. The crucible "flakes," that is, pieces scale off from the bottom and the walls to the extent that the crucible is ruined. This difficulty is avoided by annealing the crucibles before they are placed in the furnace. This annealing is accomplished by heating the crucibles to a few degrees above 212, the boiling point of water. The storage places for crucibles should always be dry and warm to prevent their absorbing water.

A great deal of the difficulty encountered with crucibles is due to neglect of this preliminary annealing, and this fact is now so well recognized that many users have special ovens in which to store the crucibles which are likely to be wanted immediately, and a sufficient stock is always kept in this oven so that no crucible is put into a furnace unless it has had several days' annealing at a comparatively low temperature. Even after a crucible has been properly annealed and is known to be bone dry it should never be placed on a bed of new coke thrown onto a hot fire in the bottom of the furnace, for the coke will contain moisture which is driven into the crucible, causing the latter to flake, in spite of the precautions that have been taken to prevent this happening.

Tilting furnaces use a crucible of a little different shape to those employed in stationary furnaces. In figure 23, the regular brass-melting crucibles are shown at the front. Those tapering upward like a bottle are retorts, and are suitable for melting aluminum. The barrel-shaped crucibles at the right are crucibles for melting steel, which are exposed to a higher temperature than those used for melting brass, and are softened by the high temperature. The barrel shape withstands the pressure of the tongs better than the open top shape

of the brass melting crucibles. Figure 25 shows two different types of crucibles used in tilting furnaces, as made by the Joseph Dixon Crucible Co., Jersey City, N. J. It will be noted that they are deeper and have a considerable projection or spout.

In its instructive little catalog entitled "Crucibles," the Jonathan Bartley Crucible Co. of Trenton, New Jersey, gives the following suggestive hints:

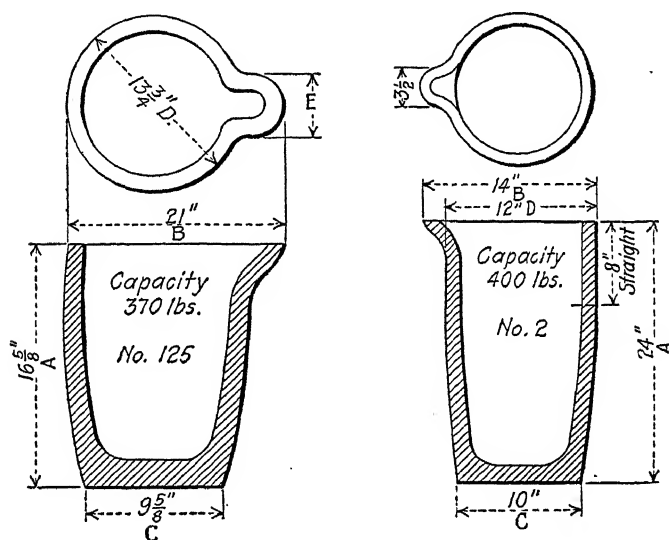


Figure 25.—Crucibles used in tilting furnaces (Dixon).

1. There are 38 sizes of graphite crucibles, from the No. 0 to the No. 400.
2. Store crucibles in a dry place, upside down, and warm carefully.
3. Gases from impure fuel are detrimental to crucibles.
4. See that tongs fit crucibles snugly, and do not squeeze them excessively.
5. Pour metal when ready.
6. Use trolleys for pouring.

FURNACES

While large quantities of non-ferrous metals are melted in crucibles, the use of non-crucible furnaces is steadily increasing. To attempt to describe the various forms of furnaces would fill a volume. Broadly speaking, we may arrange melting furnaces in three distinct types—namely, (1) solid fuel-fired furnaces, (2) oil or gas-fired furnaces, and (3) the electrically heated furnaces. These types can be subdivided into furnaces adapted for the use of crucibles to contain the metal, and furnaces that melt the metal in bulk

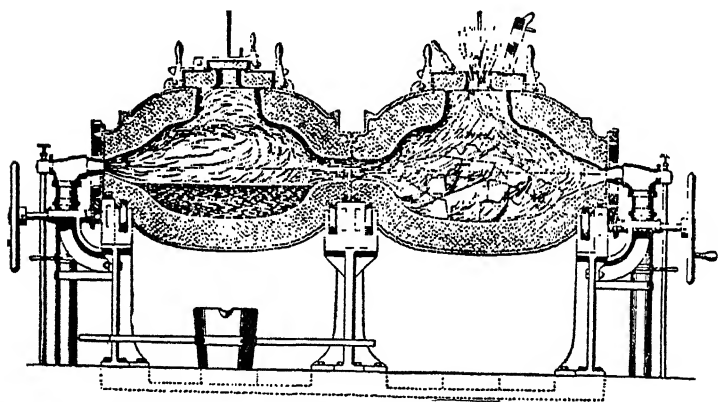


Figure 26.—The Monarch-Rockwell double-chamber oil or gas-fired furnace.

without crucibles. The crucible-using furnaces are of two kinds, namely, those from which the crucibles are removed to obtain the molten metal, and those from which the crucibles are not removed, but which are rotated on an axis to enable the molten metal to be poured out of the crucibles, into ladles, for transportation to the molds.

The oil or gas-fired furnaces melting the metal in bulk are of two types, namely, those from which the metal is tapped, and those from which it is poured, by rotating the furnace. One of the first types of this kind of furnace is the double-chamber furnace shown on figure 26. It will be noted that half of the furnace has started to melt ingot, while

the other half contains liquid metal ready to pour. This furnace is manufactured by the Monarch Engineering & Mfg. Co., Baltimore, Md. In place of the egg-shaped chambers, the tendency is now to use a simple barrel-shape, as shown in figure 27. This is the Charlier furnace, one of the first of this type. Furnaces of this shape are made by a number of manufacturers.

A furnace of quite a different type is the Hawley-Schwartz, which resembles a teapot set on trunnions. Such furnaces are efficient melters, and are capable of turning out immense quantities of liquid brass.

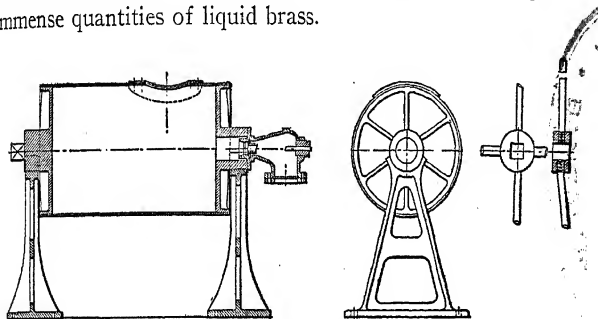


Figure 27.—Barrel type (Charlier) of furnace.

In his paper "Gas Furnaces for Melting non-Ferrous Metals," M. A. Combs* considers that the gas furnace has the lowest operating cost and is very flexible. Tilting or pit types may be used. Gas is free from sulphur, while oil is not. At present, oil is equal to, if not more expensive, than gas in fuel cost alone. Gas need not be stored like oil, but used direct from pipes. A gas furnace is considered to be more flexible than an electric furnace. Less space is occupied than by a pot furnace, and while the latter will give two or three heats a day, a gas furnace will give eight. A properly designed gas furnace has an interior diameter just large enough to admit the tongs when lifting out the crucible. Long runs with coal, oil, and gas furnaces showed that gas was by far the most economical and satisfactory fuel.

*Chem. and Met. Eng., vol. 24, 1921, p. 515.

E. L. Crosby* disputed Mr. Combs' claims, especially regarding electric furnaces, which Mr. Crosby favors, and gave figures much lower for such furnaces than those given for gas furnaces.

Reverberatory furnaces.—Another type of melting furnace to those just considered is the reverberatory. When large quantities of metal were required in olden days the reverberatory was used. These were fired with wood, and were used to melt the metal for such immense castings as the Great

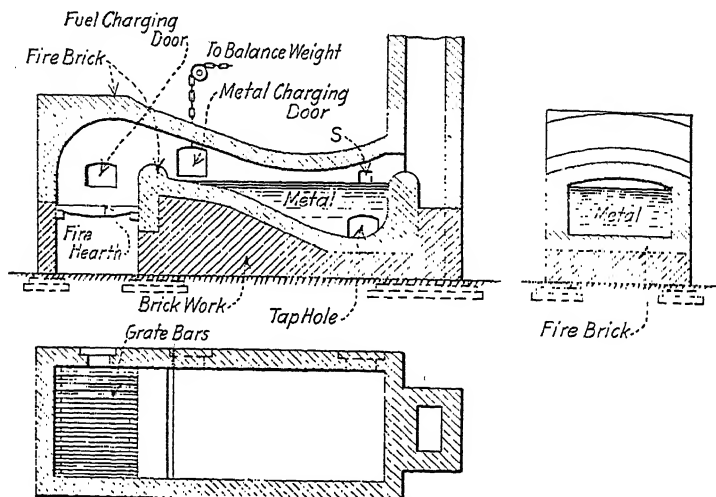


Figure 28.—Wind furnace for melting brass and gun-metals.

Bell of Moscow, which weighed 443,790 lb. In the case of this casting, four reverberatories were required to produce the molten metal. This type of furnace fired with solid fuel is most interesting, because reverberatory furnaces for the melting of bronze in large quantities have been used since the earliest times; and although superseded to some extent by open-flame oil-burning furnaces, there are still many who believe that the air furnace takes a lot of beating as a medium for melting metal on an extensive scale.

* Chem. and Met. Eng., vol. 24, 1921, p. 912.

In size, reverberatory furnaces vary from a capacity of 500 lb. to many tons. Figure 28 shows one design of this furnace, from which it will be seen that the roof is arched so that the flame from the furnace grate strikes it and is deflected onto the charge of metal, which on melting, collects in the floor or hearth of the furnace, as shown in the longitudinal cross section.

The most suitable fuel for this furnace is a bituminous coal giving a long flame and a dry ash which will not clinker on the grate-bars. The draft may be, and usually is, natural; but forced and induced draft is also employed, although not usually in the case of brass melting.

The fuel consumption in these furnaces is considered by some melters to be high, as for brass melting a smoky or reducing flame must be obtained, because with a clear or oxidizing flame the loss of metal, especially zinc, would be excessive, resulting in bad metal and high expense. It is, therefore, cheaper to maintain a smoky atmosphere at the expense of extra fuel.

When, however, a comparison is made with the crucible, it will be found that the fuel consumption is not excessive. Under favorable conditions, the average consumption of fuel for air furnaces for brass ranges from 50 to 75 lb. of coal per 100 lb. of metal, which compares favorably with the usual crucible practice. In the case of natural draft, hard coal, crucible pit furnaces, Gillett * found the fuel consumption to range from 50 to 95 lb. of coal per 100 lb. of red brass; while the coke consumption for the same type of furnaces ranged from 67 to 83 lb. per 100 lb. of the same metal.

The design of an air furnace will be governed by the amount of metal it is desired to melt at one charge, as upon this depends the area of the grate and other parts. The first things to consider are the dimensions of the bed or "sole" of the furnace, and the "pool" for containing the melted metal. The second consideration, in conjunction with the

* Gillett, H. W., *Brass Furnace Practice in the United States*, U. S. Bureau of Mines Bull. 73, 1914, 298 pages.

size of the charge and the rate of working required, governs the construction of the grate. As regards the air supply, there must be sufficient to support the combustion of the fuel, and it must also pass at sufficient velocity through the furnace

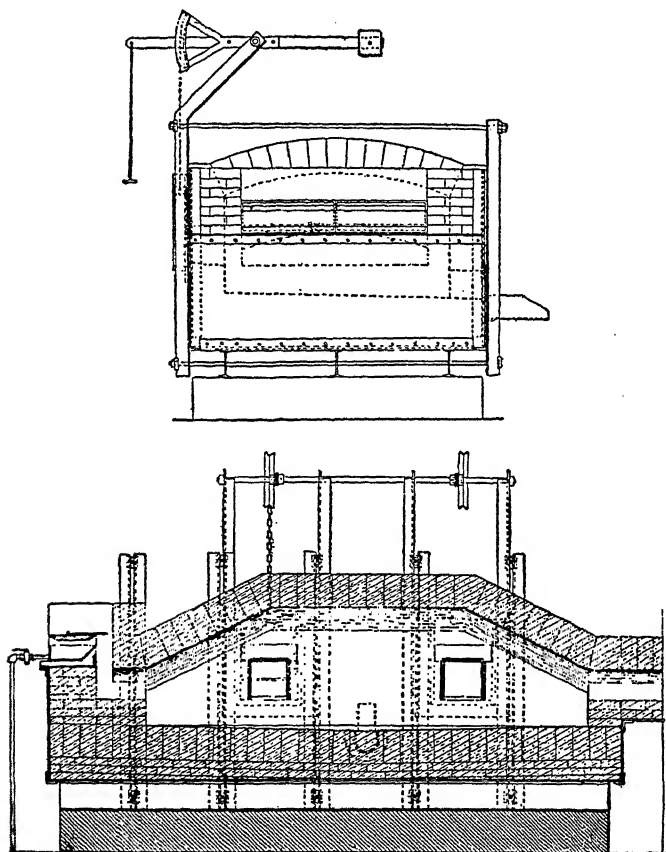


Figure 29.—Natural draft oil-fired reverberatory.

to the flue to give the necessary reverberatory effect. The current of air must be sufficiently strong for the flame to be deflected onto the metal to give the hottest effect. It will thus be seen that the shape of the furnace must bear a definite relationship to the force of the air current, otherwise the latter will not be deflected in the most effective manner. The char-

acter of the coal used largely governs the arrangement of the grate, and some authorities contend that, assuming 25 lb. of coal will be burned per hour for every square foot of grate surface, space must be allowed between the firebars for the passage of about 230 cubic feet of air for each pound of coal burned in the furnace, or 50% more than the theoretical volume required.

These furnaces are usually rectangular, although the shape of the hearth may vary considerably from the one shown in figure 28. They should all be well encased with cast-iron plates and tie-rods, as being subjected to the greatest strain when at full heat and with the charge therein they must be ensured against failure and collapse. The best materials must be used for the lining, and the firebricks and clay should not contain matter deleterious to the metals being reduced. For instance, in melting such alloys as aluminum bronze, the lining must receive careful consideration, for if highly silicious, the aluminum at the temperature of the bronze will attack the lining, and by absorbing silicon, the metal will be rendered hard and brittle. Some authorities maintain that the reverberatory furnace is not economical in fuel, and that there is a much greater loss by oxidation; therefore it is not suitable for melting highly oxidizable metals. This is a debatable point, as it is largely a matter of proper design coupled with skillful management of the furnace.

Reverberatories were once fired solely with wood, and later with soft coal. At present the firebox is frequently omitted entirely, and a burner is introduced which enables oil or gaseous fuel to be used. A furnace of the oil-fired type is shown on figure 29. It is known as a pan-burner, because the oil is simply fed by gravity to shallow pans superimposed, where it burns, and the flame is carried through the furnace, and combustion maintained by natural draft. This furnace has a capacity ranging from 500 to 70,000 lb., and is extensively used for melting nickel and monel metal because a very high temperature is attained; and in addition, it is noiseless in operation, and can be completely controlled.

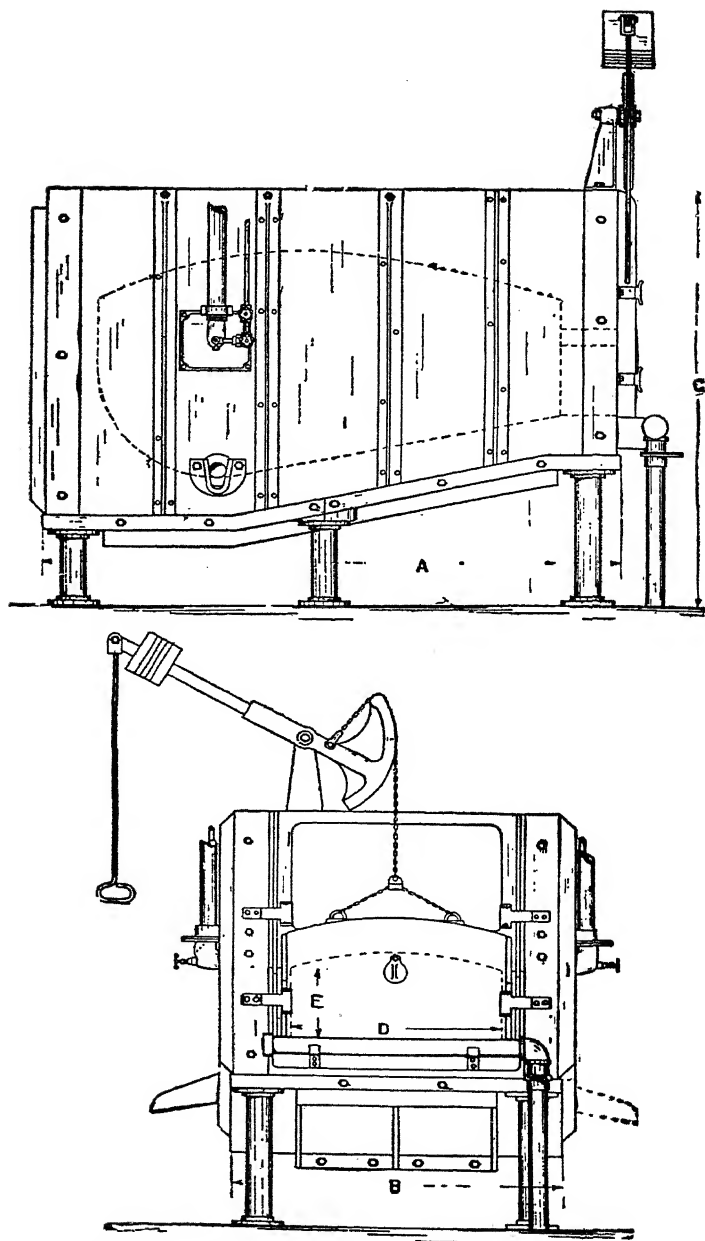


Figure 30.—Monarch oil-fired reverberatory furnace.

Another and more common type of oil-fired reverberatory is one in which the burners are inserted on either side as in figure 30, but in others of this type the burners are placed at the ends. The furnace shown is tapped to remove the molten metal, but in some makes the entire furnace is lifted at one end by suitable mechanism to permit the metal being poured out.

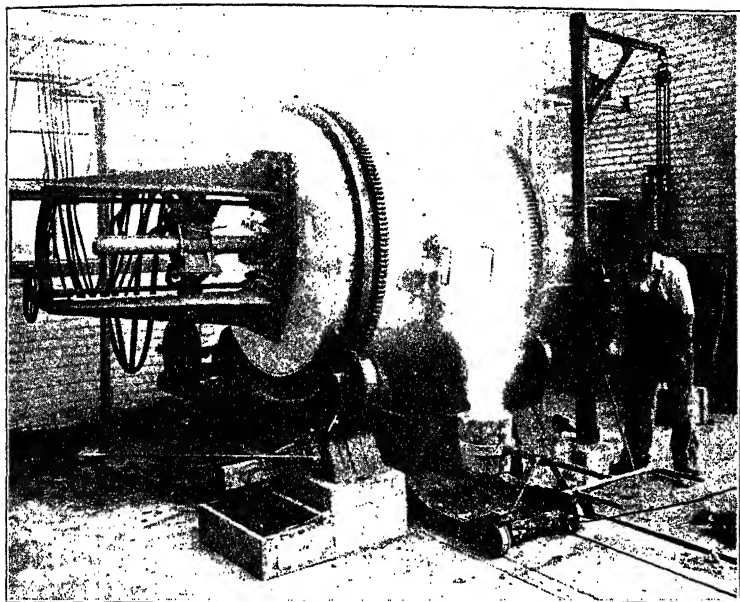


Figure 31.—A Detroit rocking electric furnace being poured.

Electric furnaces.—These furnaces also differ in design, some melting the metal by means of the radiated heat of a glower, or “granular resistor” as it is called, which being heated to a high temperature by the passage of the electric current, throws its heat onto the furnace walls, from which it is radiated onto the metals being melted. Other electric furnaces are merely large arc-lamps, the heat given out by the arc in a confined space raising the temperature above the melting point of the metal contained therein. In the non-

ferrous industry it has been found inadvisable to arc directly onto the metal, because the temperature of the arc is so high that a localized overheating takes place, which injures the metal. For this reason, even arc furnaces which arced above the metal were a failure for non-ferrous work until the investigations of Gillett demonstrated the necessity for oscillating, rocking, or revolving the furnaces during the melting period. A furnace of this type is that in figure 31, and is known as the Detroit rocking electric furnace. Rotating furnaces are also used when oil or gas is the melting medium. In electric furnaces of the arc type, the arc is now usually formed above the surface of the metal when it is melted; but before melting the pieces of metal may surround the carbons, and the arc "struck" between them. Electric furnaces that melt the metal in crucibles have also been designed, there being two types of these—namely, furnaces that generate the heat directly within the walls of the crucibles; and furnaces that consist of a well or pit, closed at the bottom, and surrounded by a resistor, which being heated by the current, warms the walls of the pit to beyond the melting point of the metal in a crucible within the pit.

Figure 32 shows the interior arrangement of a 1500-lb. hearth capacity non-ferrous electric melting furnace developed by the General Electric Co. A 50-lb. unit of similar type has also been built. Either will melt practically any metal requiring a pouring temperature not exceeding 1500° C. (2732° F.). The metal loss for yellow brass is less than 1.5%, and for red brass under 0.75%. The large furnace will give one heat per hour, consuming 270 kw.-hours per ton, or 19 tons of metal in 24 hours. They work on the muffled-arc principle.

An interesting type of electric furnace is that built by the Volta Manufacturing Co., of Welland, Ontario, of which an illustration is given in figure 33. This furnace resembles the oil and gas-fired melting furnaces. It has three electrodes which enter the furnace above the charging zone, and during the period of melting the metal is constantly mixed by means

of a gyratory movement of the furnace which is shown by figures 34 and 35.

The metal is melted by the radiated heat from the arc between the electrodes. As the electrodes are placed at a proper height above the metal, this radiated heat is thoroughly diffused over the metal bath, and, on account of the latter being shallow, this heat is readily absorbed. Heat radiated against the roof of the furnace is reflected back down on the

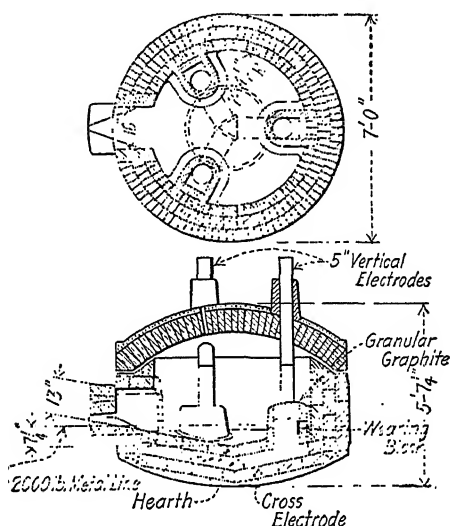


Figure 32.—Interior arrangement of 1500-lb. hearth capacity non-ferrous melting electric furnace.

metal on account of the special shape of the roof, none of the heat from the roof being radiated against the walls.

Remembering that the heat applied in brass furnaces should be diffused through the metal as quickly as possible, this furnace is so designed as to give a very shallow bath, so that the heat from the arc is more readily taken up by the metal.

The design of this furnace and the gyrating movement is particularly advantageous where it is desired to pour ingots direct from the furnace, which is accomplished in the follow-

ing manner: When the metal is ready for pouring, the furnace is turned until the mouthpiece attains its highest position, the furnace is momentarily stopped, and the plug in the tap-hole is opened. The motor is then started again, and the mouthpiece is lowered to any point so that the metal will flow out in any desired stream—the position of the mouthpiece during the whole operation varying very little, so that ingots can be readily poured.

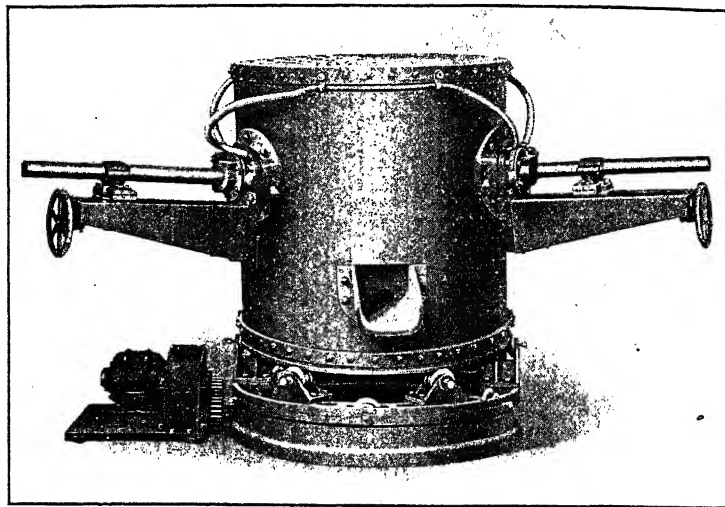


Figure 33.—New type of electric furnace for melting non-ferrous metals (brass).

Precautions when melting.—It is important, when melting in non-crucible furnaces, to so adjust the oil and air that the flame will not be too strongly oxidizing. Some operators favor a reducing flame—that is, one deficient in oxygen, and consequently smokes a little.

A small portion of the heat, which otherwise could be used for melting the metals, is sometimes lost thereby; but the great advantage is gained that as long as the gases of combustion passing over the metals absorb oxygen, the melting metals will actually remain in a metallic state. This is especially of great importance with metals which readily

oxidize when exposed in a fused state to the action of the air. It may be remarked here that the oxides formed from the metals as a result of careless work seldom take part in the formation of the alloy, so that even if the quantities of metals have been accurately weighed, the resulting alloy will not show the desired composition, since the portion of the metals converted into oxide does not enter into the alloy.

For preparing alloys on a smaller scale in a crucible, special precautionary measures must be taken against oxidation of the metals. For this purpose the surface of the metals is covered with materials which prevent the access of air, without, however, exerting any influence whatever on the metals, or at least only to a very small extent thereupon. In many cases anhydrous borax is used; but independently of the fact that borax is rather expensive and unnecessarily increases the cost of the alloys, its employment is accompanied by many evils. It is well known that in borax a portion of the boric acid is not perfectly saturated, and that in melting borax with base metals a certain amount of the acid is always absorbed, which, with the sodium borate, forms double salts of a glassy nature. Hence, by fusing metals under borax, some of them will be lost by combining with the borax.

Glass consists of a mixture of silicates; and forms, when thrown upon fusing metal, a coating which completely excludes the access of air to the surface of the metal. Though it has also the property of absorbing certain metals when brought in contact with them in a liquid state, the influence it exerts upon alloys is, generally speaking, much less than that of an equal quantity of borax. If the metals to be fused together are such that a combination with carbon need not be feared, the fusing mass can also be protected from the influence of the oxygen of the atmosphere by covering it with a layer of granular charcoal. Many foundrymen throw a certain quantity of fat upon low-melting point alloys before fusion. This fat, on being suddenly strongly heated, decomposes and evolves a considerable quantity of gas, which exerts a protecting influence on the surface of the metals. After

the evolution of gas has ceased, there remains a very finely divided carbon which protects the metals from oxidation.

Mixing alloy metals.—As stated in the introduction to this chapter, in preparing alloys, the metal most difficult to fuse should be melted first, and the more fusible ones added only after complete fusion of the former, although there are some exceptions to this rule. The varying densities of the metals to be combined frequently render the formation of a homogeneous mass very difficult; moreover, in many alloys, certain chemical combinations are readily formed, while the

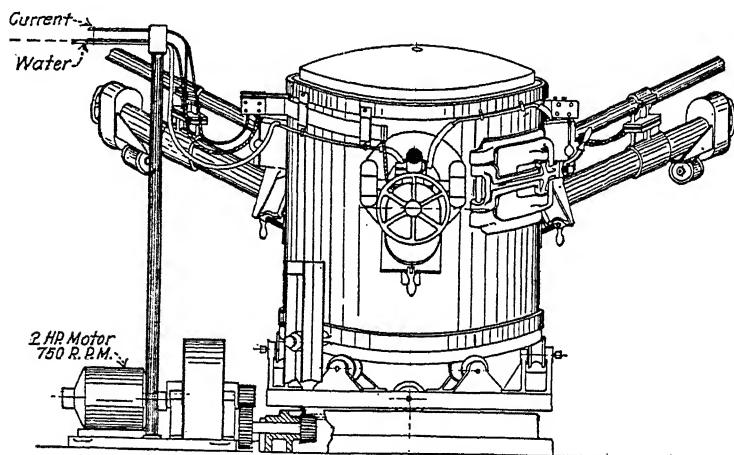


Figure 34.—Motor drive of Volta furnace

remainder of the metals form alloys, the preparation of which was not intended.

If two metals with greatly varying densities are alloyed, and the mass is allowed to be quiescent, it will be observed that after cooling and taking the alloy from the crucible it shows clearly perceptible layers varying in color and appearance. By chemically examining these layers it will be found that each of them contains different quantities of the metals used in alloying. To obtain, in such cases, as homogenous an alloy as possible, the metals, while in a state of fusion, must not be allowed to remain quiescent, but must be intimately mixed by stirring. In the case of some alloys this can be

done with an iron bar; but it is better with most bronzes to use a stirrer of graphite, which is fixed to a handle. In making phosphor-bronze, graphite stirrers should always be used, as the phosphorus strongly attacks the iron, which is dissolved, and entering the alloy, lodges in the castings as dross. Iron is suitable for stirring manganese and aluminum bronze, as these alloys generally contain iron, and a little more or less is not especially harmful. The use of wood for stirring metals melted in crucibles is not practicable on account of the

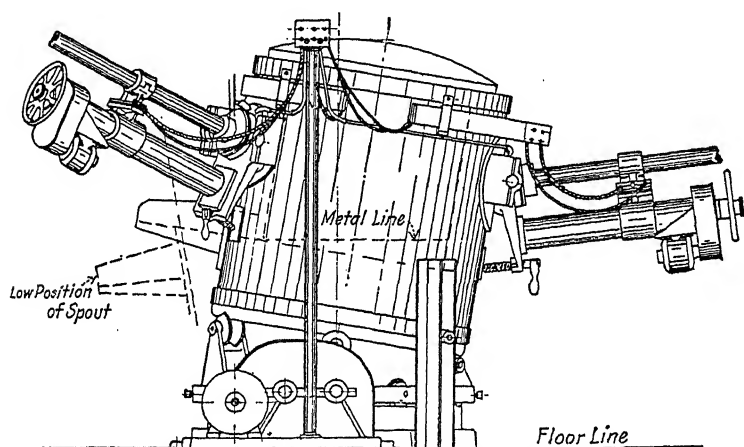


Figure 35.—Angle assumed as Volta furnace gyrates.

disturbance created by the gases liberated from the burning wood, the result being the violent ejection of a portion of the metal. In figure 36 are shown a number of stirrers and skimmers as made by the Joseph Dixon Crucible Co. The special mint stirrer at the lower left is a pump stirrer that should be used for thoroughly mixing metals of widely different specific gravity, such as aluminum bronze.

The production of proportionate solutions of the metals one in another in melting can sometimes be promoted by certain manipulations—for instance, the process of allowing the alloy to cool and then re-melting it. Scrap and waste generally result from casting, and which in order to be

utilized these have to be re-melted. So-called old metal, consisting of articles which have become useless by having been broken or otherwise damaged, are also frequently re-melted. The above-mentioned effect of re-melting accounts for the fact that a moderate addition of such scraps, provided they consist of the same alloy, may be beneficial as regards the properties of the alloy to be melted. However, the metals chiefly used for alloying are readily oxidizable in the melting temperature, and many of them possess the property of dissolving their own oxides whereby their usefulness may be impaired. The more frequently the alloy is re-melted the more ample the opportunity for the absorption of oxides will be, so from this it will be seen that the melting of old metal without the addition of fresh metal is only possible without producing an injurious effect when no oxides are absorbed during melting. No rule can be laid down regarding the proportion of old to new metal most suitable for the production of serviceable alloys, since the old metal has, as a rule, been more or less often re-melted.

When larger quantities of one metal are to be alloyed with smaller quantities of another, it is advisable first to melt together approximately equal quantities by weight of the two metals, and by a second melting combine the resulting alloy with the remainder of the metal. This method is frequently employed when there is considerable difference between the melting temperatures of the metals. If, for instance, a small amount of copper is to be alloyed with a large quantity of tin, an alloy, the melting temperature of which will be considerably lower than that of copper, is first made by melting the copper together with about the same quantity by weight of tin, and then adding the remaining tin. The same method is adopted when three or more metals of different melting points are to be alloyed in varying proportions by weight. To make, for instance, an alloy from 3 parts lead (melting point 618.8° F.), 1 part tin (melting point 446° F.), and 1 part antimony (melting point 1166° F.), the most suitable process is first to alloy one-third—that is, 1 part of the lead

with the entire quantity of antimony by dissolving the latter in the lead after it has been melted, then adding the rest of the lead, and finally combining with this lead-antimony alloy the tin which is most readily liquefied. Being the most expensive of the three metals, oxidation of tin should be prevented as much as possible. The same object might also be accomplished by alloying one part of the lead—as previously described—with the antimony, another part of the lead—or under circumstances the entire remainder of it—with the tin, and then combining the lead-antimony alloy with the lead-tin alloy.

When a larger amount of copper (melting point 1983.2° F.) is to be alloyed with smaller quantities of nickel (melting point 2732° F.), and zinc (melting point 779° F.), one part of the copper may first be melted together with the nickel and another part with the zinc, finally combining the nickel-copper alloy with the zinc-copper alloy. The reason for this apparently more troublesome process may be found in the fact that, on the one hand, uniform combination is facilitated by the formation of intermediate alloys with melting points less far apart than those of the constituent metals; and, furthermore, that readily oxidizable or volatile metals—zinc, for instance—are less subject to oxidization or volatilization when alloyed than when in a pure state.

While formerly only a few alloys were known, a large number are at present used in the industries, and we find rare metals sometimes employed for the preparation of alloys to impart special properties. One of the principal causes of this advance in the art of alloying is the progress of mechanics; and regarding the properties of alloys, we need only consider the bearings of shafting and axles in order to understand the varying demands made by the engineer. How different must be the nature of an alloy which serves for the construction of the bearing of an axle revolving with a light load perhaps once in a second, from that which has to bear a heavily-loaded shafting making many hundred revolutions per minute? Alloys possessing great ductility are required

for many purposes; for others the chief requisite is hardness; others again must have a high degree of elasticity; and still others as low a melting point as possible. It will be readily understood that these different demands can only be satisfied by adding to the alloys suitable quantities of metals of varying properties.

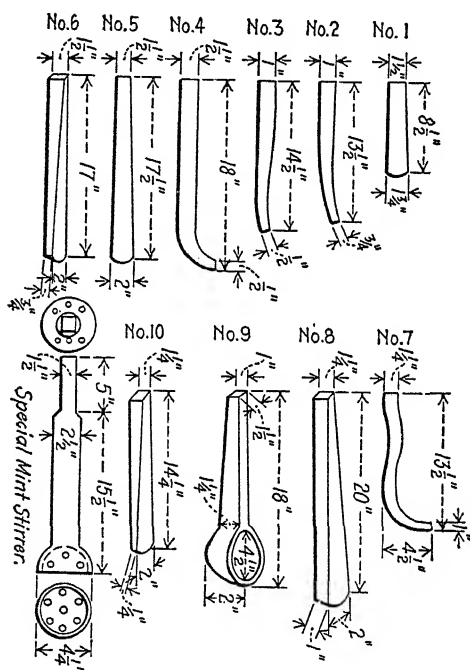


Figure 36.—Graphite stirrers and skimmers.

Though most heavy metals are at the present time used in the manufacture of alloys, copper, tin, zinc, lead, silver, and gold are more frequently employed than others, the alloys of these metals being at the same time those which have been longest known and used. In modern times the alloys prepared with the assistance of nickel have also become of great importance, as well as those of which aluminum forms a constituent.

Everybody who studies alloys closely knows that the

amount of information which has been gained upon this important branch of metallurgy is comparatively meager and that much is still to be expected from the progress of chemistry. The non-technical man, if left to himself, cannot be expected to arrive at certain results, because, probably, he may be wanting in chemical knowledge, or in the methodical course of investigation which must be possessed by those who are qualified to prosecute such investigations successfully. These qualifications are so much the more indispensable when it is remembered that every new alloy, by the fact of its properties being different from those of its constituents, may be regarded as a new metal.

Before proceeding with the description of the most important alloys, it will be in order to discuss briefly the best methods of making experiments in the preparation of new alloys.

It is known that the elements always combine with one another in certain quantities by weight, which are termed atomic weights. (See table of atomic weights of the elements in Chapter I.) By mixing the metals according to equivalent quantities, alloys of determined characteristic properties are, as a rule, obtained. If these properties do not answer the demands made of the alloy, the object is frequently attained by taking two, three, or more equivalents of one metal. An exception to this rule is only made in certain cases, and especially where, according to experience, a very small quantity of a metal suffices to change considerably the properties of the alloy. It is then most suitable to prepare the mixtures serving for the experiment according to thousandths, and with every new experiment change the proportion between the separate metals a certain number of thousandths.

For combining metals with non-metallic elements—with sulphur or phosphorus, for instance—it is, however, not sufficient to choose the proportions according to thousandths, it being necessary to add these bodies according to ten-thousandths. For these elements, the form in which they are used is also of importance, which, however, will be referred

to in discussing them later on. It may be remarked here that the application of the term alloy to such metals which, so to say, are contaminated by phosphorus or sulphur, is entirely incorrect. It is used, however, for want of a better term, since it at least indicates that we are not dealing with a pure metal.

CHAPTER VI

COPPER AND ITS ALLOYS

ON account of its great ductility and tenacity, pure copper is a very important metal for various applications in the arts, but its employment for many purposes is attended with difficulty. However, certain alloys of copper possess, in addition to the valuable properties of the latter, others which render them especially suitable for certain industrial purposes; and moreover, it is possible to impart to such alloys the most desirable properties, as they can be made soft or very hard, brittle or elastic, malleable or non-malleable, and so forth.

Effect of impurities.—The production of copper alloys is attended with certain difficulties, since this metal has a high melting point, and very small quantities of foreign substances exert a great influence on its own properties as well as on those of its alloys.

Iron exceeding $\frac{3}{1000}$ (0.003%) has an injurious effect upon the properties of copper, rendering it hard. Antimony and arsenic mixed with copper considerably decrease its property of ductility. Copper containing only $\frac{1}{1000}$ (0.001%) of antimony can no longer be worked for sheet brass. Bismuth acts in a manner similar to antimony. Zinc mixed with copper up to $\frac{6}{1000}$ (0.006%) makes it red-short. Certain alloys of copper and zinc can, however, be easily worked, the most important of such alloys being brass. Tin and silver do not seem to have any injurious effect on the properties of copper, and these two metals, if added in certain proportions, yield alloys which are distinguished by specially valuable properties.

An admixture of cuprous oxide makes copper both red-short and cold-short, especially if present in large quantities;

and further, imparts to the copper the undesirable property of contracting considerably in casting. Moreover, the castings from such copper show an unequal density, so that plates cannot be used for copper-plate printing. It may be remarked here that most commercial brands of copper contain certain quantities of cuprous oxide, it being claimed that an admixture of 0.05 to 2% is even beneficial, as it counteracts the injurious influence of foreign metals upon the copper.

Besides the above-mentioned impurities, many brands of copper frequently contain non-metallics, such as sulphur, silicon, and phosphorus, whose influence is, as a rule, very injurious, as will be discussed below:

Sulphur renders the copper red-short, and castings are blown. With silicon, copper loses its red color and acquires one shading into white, its ductility being at the same time considerably affected. Copper containing nearly 2% of silicon can only be rolled in the cold, as it cracks when hot. Phosphorus exerts a considerable influence on the properties of copper, generally increasing its hardness, at the same time making it more fusible. With an admixture of $\frac{1}{1000}$ (0.001%) of phosphorus, the copper can only be rolled in the cold, while with a still greater amount it becomes brittle in the cold. Some alloys of copper with phosphorus, known as phosphor-bronze, are, however, used for certain industrial purposes on account of their special properties, they being distinguished by particular strength, ductility, and beautiful color. These combinations will be referred to later on.

According to investigations by Hampe, copper shows the following behavior towards admixtures:

With between $\frac{2}{1000}$ (0.002%) and $\frac{22}{1000}$ (0.022%) of cuprous oxide, the properties of the copper are not sensibly affected, it becoming red-short only in the presence of $\frac{87}{1000}$ (0.067%); and this compound always acts in such a manner as to increase the brittleness of the metal more in the cold than in the heat. Arsenic ($\frac{1}{1000}$ or 0.001%) exerts no influence on copper, but $\frac{20}{1000}$ (0.020%) of it render it cold-short and hard. It only becomes red-short with $\frac{10}{1000}$

(0.010%) of arsenic, but is not cold-short, which is contrary to the opinions formerly held in regard to the influence of arsenic upon copper. Antimony acts similarly to arsenic, except that a smaller quantity of it will make the copper red-short.

Lead to the extent of $\frac{15}{1000}$ or 0.015% exerts no influence upon the properties of copper; a slight brittleness in the heat shows itself, however, with $\frac{3}{1000}$ (0.003%), which becomes greater with one of $\frac{4}{1000}$ (0.004%), and is clearly perceptible in the cold.

Hampe also found that bismuth exerts an especially injurious influence upon the properties of copper, a very small quantity sufficing to decrease the ductility in the heat, while with $\frac{5}{1000}$ (0.005%) the copper becomes exceedingly red-short and sensibly cold-short.

A considerable proportion of commercial copper is extracted from copper minerals associated with a number of other metallic minerals, this holding especially good in regard to those brands obtained from gray copper ore.* Experts can tell from the external properties of the metal, especially by the color, fracture, and ductility, whether it is suitable for certain purposes or not; but it is, of course, impossible to recognize in this manner the amount of foreign elements, so in buying a large lot of copper for alloy purposes it is best to sample it thoroughly for chemical analysis, in order to be sure that it is free from lead and bismuth.

As previously mentioned, the number of copper alloys is large, the most important being those with aluminum, tin, zinc, nickel, gold, silver, platinum, and mercury. The alloys of copper with lead, antimony, and iron are less frequently used.

After giving a brief sketch of the alloys of copper with the precious metals, which have been used from very remote times, we will first discuss the alloys of copper with the base metals, they being of special interest for industrial purposes,

* It contains copper, antimony, arsenic, and sulphur.

and, besides, presenting more technical difficulties in their preparation.

Copper-gold alloys.—Gold having but a slight degree of hardness must be alloyed with other metals to prevent its wearing too rapidly, so copper and silver, either alone or together, are generally used. Besides the fact that gold alloys show a greater degree of hardness than the pure metal, the color of the latter is also changed by alloying with silver or copper, there being gold with a color shading into white (alloyed with 30% silver), a green gold (alloyed with 64% silver) and other varieties shading into red (alloyed with copper). The preparation of alloys of gold and silver has become very extensive on account of their being used for coinage and articles of jewelry, which is fully discussed in Chapter XXI.

Copper-silver alloys.—The alloys of copper with silver are extensively used for coinage and silverware. As may be seen from the properties of both metals, these alloys possess a considerable degree of ductility, and if the proportions in which the metals are mixed are so chosen that the copper slightly predominates, their properties are almost exactly a mean between those of the two metals. They will also be fully discussed in Chapter XXI. Most alloys of silver and copper contain more of the former than of the latter metal.

The alloys of the other precious metals, especially those of the platinum group, find only a limited application in the industries, and will be referred to in Chapter XXI.

Alloys of copper with base metals.—Although there are a large number of alloys of copper with the base metals, those known under the general terms of brass and bronze are so extensively used as to make most of the others appear unimportant in comparison. Bronze has been known from very remote times, and was used by the ancients in casting statues and other ornaments. The bronze used in those days contained no lead, and came nearest to what is at the present time designated by the term bronze—that is, an alloy of copper and tin. The bronze used by the Romans and after them

was rarely an alloy of pure copper and tin, but contained usually more or less lead.

Brass, the other important alloy of copper, was manufactured by cementing sheets of copper with calamine or zinc carbonate long before zinc in a metallic form was known.

Copper castings.—By reason of its great ductility and tenacity copper forms a very important and valuable material for purposes of machine construction. In the form of castings it is extensively used, but it has always been regarded as a difficult metal to cast on account of the facility with which it absorbs gases which are retained in the castings, thus making them porous instead of sound in structure.

To obtain castings free of gas-holes, it is necessary to add some metal or non-metal to the copper that will either remove the gases or increase their solubility in the copper; in both cases the result being the same, that is, solid castings. Such additions considerably affect the purity of copper for some purposes, mainly electrical, but for other purposes, the impurity does no harm, because the castings are to be used merely because a material having the mechanical properties of copper is desirable. This distinction divides copper castings into two classes, namely, high electrical conductivity copper castings, and mechanical copper castings.

In the first class of castings are all those used for conveying electrical current, and in the second class, those such as blast-furnace tuyères, which carry no current, but are made of copper because of the ductility, heat conducting, and heat resistive properties of the copper.

Of these two classes of copper castings, those having a high electrical conductivity are the more difficult to make; in fact, it is only within fairly recent years that the problem of how to make such castings has been solved, and even now there is much to be investigated.

The conductivity of copper has always been expressed as a percentage of the conductivity of silver, which was rated at 100. It has been discovered, however, that the lower conductivity of copper is due to the original samples having been

imperfectly purified. Modern cathode copper frequently is more than 100% in conductivity. According to Lawrence Addicks,* by common consent conductivity has come to be expressed in percentage of the value of 0.141729 international ohm at 0° C., found by Matthiessen for a meter-gram of supposedly pure copper over 50 years ago. Based on this, the Specifications of the American Society for Testing Materials have established a minimum requirement equivalent to 98.5% conductivity for wire bars and cakes, and 99.5% for ingots, determinations to be made upon annealed samples. The average copper on the market, according to Addicks, runs higher in conductivity than the above specifications. Much copper has over 100% conductivity as compared with the imperfectly purified Standard copper of Matthiessen. The purest copper—an unannealed sample of wire drawn directly from a cathode without melting—may run over 102% conductivity; it is unusual for copper that has been melted to run over 101%.

Deoxidizing copper.—One of the first methods for making cast copper mechanically sound and of high electrical conductivity was that of E. Weintraub of the General Electric Co. This process, which he claims he accidentally discovered, consisted in a method of treating molten copper with a lower oxide of boron, and later with carbide of boron. This material was simply a powdered “flux” known as boron suboxide, which was produced by reducing boric anhydride (B_2O_3) by magnesium, which reduced the oxide of boron to a lower oxide; one containing a smaller percentage of oxygen, therefore, known as boron suboxide. When heated in contact with oxygen, this suboxide took up more oxygen and reverted to the regular oxide of boron. The “boroflux,” as it came to be known, was a mixture of boron suboxide, and boric anhydride, magnesia, and possibly some magnesium. About 1% of the boroflux was used, which contained around 0.10% of boron suboxide. In order to get the best results

* “Copper Refining,” 1st ed., 1921, 211 pp. McGraw-Hill Book Co., New York.

with this flux it was necessary to heat the copper strongly. The flux was sometimes divided into two parts, one part being placed in the bottom of the crucible mixed with charcoal, and the other half added to the molten metal and thoroughly stirred in. It is necessary to get the flux into the copper, otherwise it is not effective, as it simply floats on the surface and takes up oxygen from the atmosphere instead of from the copper. Failures with the flux can be attributed to the fact that it has not been properly brought into contact with the copper, or that the addition was insufficient to remove the oxides, owing to the fact that the original copper was too highly oxidized at the start.

A different method of deoxidizing copper to produce castings of high conductivity has recently come into extensive use, namely treating the copper with an alloy of magnesium, calcium, and silicon with copper, in which the proportions of the first three are adjusted to produce silicides of magnesium and calcium, which, when heated in contact with oxygen will take up the element and be changed to silicates. The first combination experimented with, which was only partly successful, was composed of 5% calcium, 7% silicon, and 88% copper, and 0.75% was added to molten copper. This alloy was devised by the author, and was used in the proportions given above, and in numerous other proportions of the active elements, calcium and silicon, in making commercial castings of copper for a number of years. When used in private practice by operators who thoroughly understood its peculiarities, success attended its use; but when it was commercially exploited it proved a failure; and on account of the experience thus gained, the alloy was radically changed, other elements being added thereto with the result that a dependable alloy for ensuring soundness in cast copper of high electrical conductivity was finally obtained.

An electrical conductivity of, from 80 to 90% can now be expected in the case of copper castings, by the use of the two modern copper deoxidizers, boroflux or the silico-calcium copper alloy. The former is manufactured by the General

Electric Company, and the latter by Alloys & Products, Inc., of New York City.

The influence of impurities on the electrical conductivity of copper has been systematically studied by Addicks, who used wire of 99.50 to 101% conductivity in making his ingots. This wire of known conductivity he melted in a reducing atmosphere under charcoal, then added the impurity the influence of which he wished to study. The copper was next cast into an ingot in a heated iron mold, and the ingot

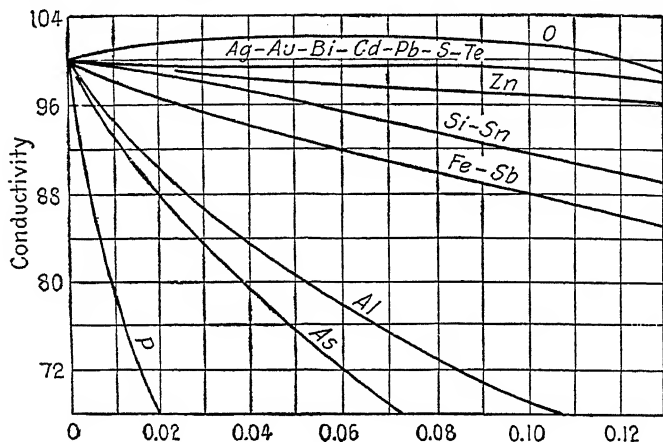


Figure 37.—Effect of impurities on the electrical conductivity of copper (after Addicks).

was swaged down and drawn cold to No. 12 B. & S. gage wire. This wire was then annealed by passing a current of 110 amperes through it, which heated and so softened it. The wire was then tested for conductivity. A summary of the results of these tests is presented in the diagram on figure 37. While the presence of all the impurities experimented with lowered the conductivity of the copper, it will be noted, remarked Addicks, that those elements—such as lead, bismuth, and tellurium—which are known to make copper brittle, have but slight effect upon the conductivity; while those which make excellent bronzes—such as phosphorus, aluminum, and silicon—cause a marked depression in the conductivity curve.

To remove the gases, and so make solid copper castings possible, would appear on the face of it a simple problem; but unfortunately it is not as easy as it seems, because, whatever element is added to the copper, it is not possible to gage it with such accuracy that after the deoxidizing has been accomplished, none of the element will remain in the copper. The reason for this is because the oxygen content of the copper is an unknown and variable quantity, and the same is true of any other gases it might contain, such as sulphur dioxide, oxides of carbon, or other gaseous bodies. It is necessary to use an excess of the deoxidizer, and this excess alloys with copper and constitutes an impurity which lowers the conductivity. It follows then that it is impossible to add any element to the copper and increase the conductivity of the metal.

Sometimes it requires a considerable amount of the deoxidizing element to ensure soundness in sand-made castings of copper. For instance, when zinc is added for this purpose, it will require about 3% to ensure sound copper castings, if the zinc is added in the metallic form. If the zinc is added as an alloy with copper, such as a yellow brass or a 50-50 copper-zinc alloy, then an addition of 1% zinc in this form may result in sound castings; but this will depend to a large extent upon the care with which oxidation was prevented during the melting period.

One of the first investigators to appreciate the importance of producing solid copper castings of a high degree of purity was Mushet in England; and although this was long before the necessity for electrical conductivity, his patented formulas are of interest. The alloys used by Mushet follow:

1. Copper, 100 lb.; zinc, 2 oz.
2. Copper, 100 lb.; zinc, 2 oz.; antimony, 4 oz.
3. Copper, 100 lb.; arsenic, 8 oz.
4. Copper, 100 lb.; zinc, $\frac{1}{2}$ oz.; tin, $\frac{1}{2}$ oz.
5. Copper, 100 lb.; antimony, 1 oz.; arsenic, 1 oz.
6. Copper, 100 lb.; tin, 1 oz.; antimony, 2 oz.

For "mechanical" copper castings, the following alloy is recommended because it produces an easy-to-cast copper that gives the minimum of trouble in the foundry: Copper, 92%; 70-30 sheet brass clippings, 7%; and 5% phosphor-tin, 1%.

The above formula produces a copper that will give the minimum amount of trouble from shrinkage and other defects.

Silicon copper is also used extensively to produce sound copper castings, an alloy of 90% copper, and 10% silicon

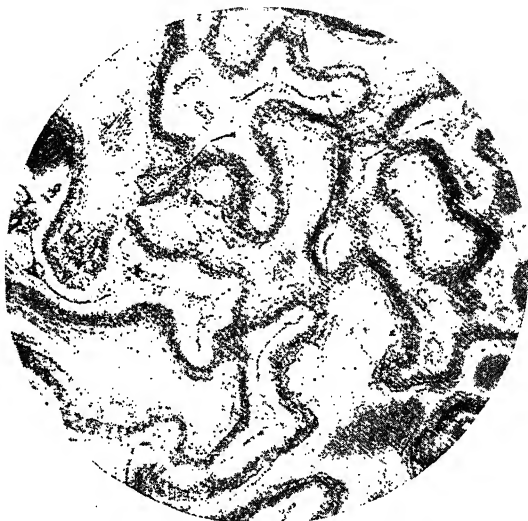


Figure 38.—Four per cent silicon copper. ($\times 100$.)
Etched with ammonium hydroxide and hydrogen peroxide.

being the one most frequently used. This alloy is brittle. The structure of silicon copper is shown by the microphotographs (figures 38 and 39), which show an alloy with 4% and 10% silicon, respectively. The 4% silicon copper is about as hard as a 10.50% aluminum bronze, but is not of use as an alloy. It illustrates the hardening effect of silicon on copper, which is about twice that of aluminum.

In using silicon copper to make sound copper castings for mechanical purposes, sometimes 2% and over of the 10% silicon copper is added. This is entirely too much,

and will result in one of two things: either an unnecessary excess of silicon alloyed with the copper, or the condition shown by the microphotograph (figure 44) where a large amount of silica or sand is left in the casting.

To determine just how much silicon copper was necessary to produce sound castings of copper melted in crucibles under ordinary foundry conditions, the author of this volume carried out the following experiments:

Experiments with silicon in copper

Run number	Mixture	Results and discussion
1	Scrap copper, 100 lb. 10% silicon copper, 16 oz.	Perfectly sound castings, and cast with little drossing. This is the maximum amount of the 10% silicon copper which should be used to make copper castings.
2	Scrap copper, 100 lb. 10% silicon copper, 12 oz.	Sound castings.
3	Scrap copper, 100 lb. 10% silicon copper, 8 oz.	Sound castings.
4	Scrap copper, 100 lb. 10% silicon copper, 4 oz.	Castings solid, but the copper did not cast as well as when more silicon was used. This is the minimum amount of 10% silicon copper it is advisable to use when melting in crucibles and using scrap copper.
5	Scrap copper, 100 lb. 10% silicon copper, 2 oz.	Head of the pouring sprue swelled slightly, and when cut, the castings showed pin-holes. This quantity of silicon is insufficient to produce sound castings in crucible melting.
6	Scrap copper, 105 lb. 10% silicon copper, 1 $\frac{3}{4}$ oz.	Castings showed a few pin-holes. This experiment, together with No. 5, showed that 4 oz. of 10% silicon copper is the minimum amount that can be used to make sound castings of copper with this deoxidizer; but that 6 oz. per 100 lb. of copper will produce a better casting mixture.

When copper is melted in reverberatory furnaces, or non-crucible furnaces which permit of the molten copper being poled to remove oxide before the addition of silicon copper, a much smaller percentage of the deoxidizer can be used to make good castings, and this method is used commercially to produce high conductivity castings, using silicon. As the

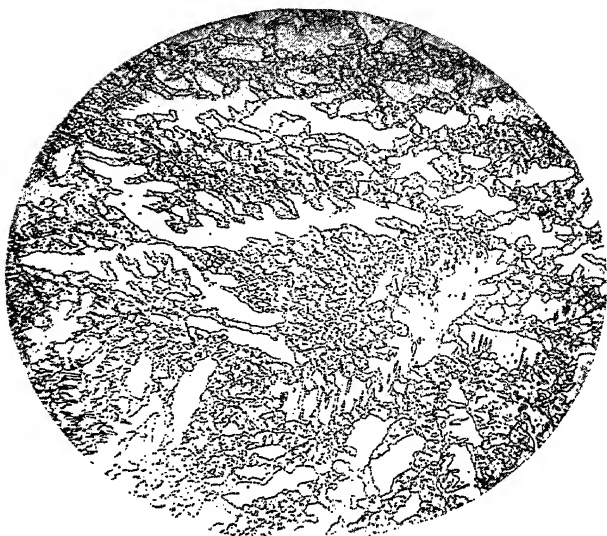


Figure 39.—Ten per cent silicon copper. ($\times 100$.)
Etched with ferric chloride and hydrochloric acid.

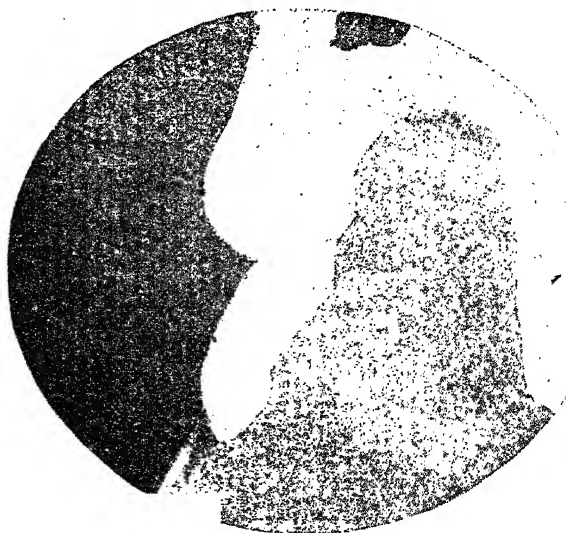


Figure 40.—High conductivity cast copper. Large
crystals show only trace of oxide. ($\times 100$.) Etched
with ammonium hydroxide and hydrogen peroxide.

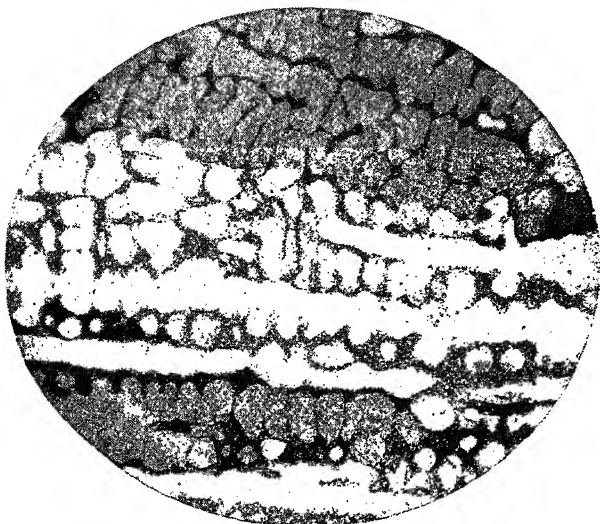


Figure 41.—Badly oxidized copper; called “boron copper.” Shows large amount of dark oxide eutectic between and within copper crystals. ($\times 100$.) Etched with ammonium hydroxide and hydrogen peroxide.

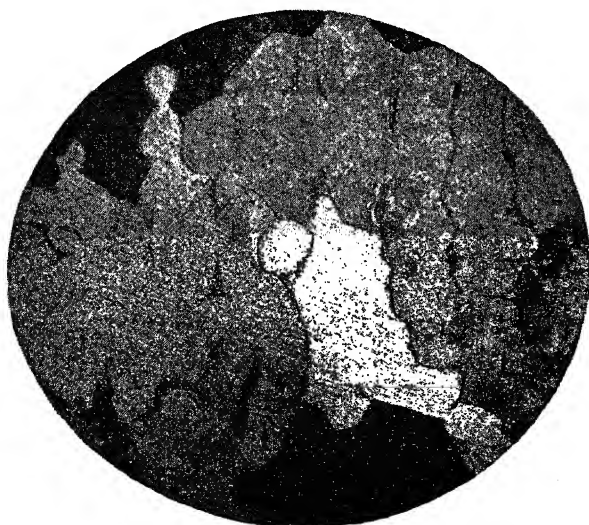


Figure 42.—Badly oxidized electrolytic copper ingot. Curved dark bands are cuprous oxide eutectic, between and within crystals of copper. ($\times 100$.) Etched with ammonium hydroxide and hydrogen peroxide.



Figure 43.—Pure Raritan ingot copper. The globules are cuprous oxide. Unetched.

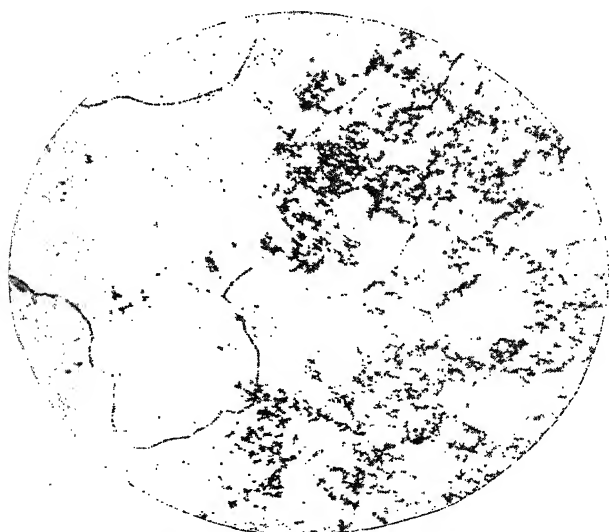


Figure 44.—Cast copper of poor conductivity. Shows inclusion of silica. Excess of silicon copper used to deoxidize. ($\times 100$.) Etched with ammonium hydroxide and hydrogen peroxide.

percentage of silicon is so low—if the molten copper en route to the molds is unduly exposed to the atmosphere—the castings will be unsound, therefore, for the purer classes of copper castings, the methods previously outlined are the best.

Figure 40 shows a cast copper of high conductivity. Only traces of oxide are visible. The deoxidizer used was 0.75% of an alloy of 7% silicon, 5% calcium, and 88% copper.

Figure 41 shows a copper containing a large amount of oxide (the dark areas). This sample was cut from an ingot supplied by the makers of what is termed “Boron copper,” and is supposed to be valuable as a “deoxidizer” of copper and copper alloys.

Figure 42 shows oxidized electrolytic ingot copper, and figure 43 a refined electrolytic copper ingot. The specks are cuprous oxide, a certain amount of which has to be left in the copper in order to get it at what is known as “tough pitch,” at which stage it possesses its best properties.

Figure 44 shows a cast copper of poor conductivity. This sample was deoxidized with silicon copper, used to excess. The original copper, however, contained a large amount of oxide, otherwise there would not have been so much silica (the oxide of silicon) left in the copper. An excess of this oxide is very detrimental in machining the copper, because, being nothing but sand, it wears away the edges of the tools used in cutting the copper. Also, it impairs the conductivity to a large extent.

CHAPTER VII

ALUMINUM AND ITS ALLOYS

THE subject of aluminum and its alloys has grown so extensive that to do it justice an entire volume would be required, therefore, a work covering all of the metals can only touch the high spots. In Chapter II, the section on the element aluminum outlined how the metal is produced, and briefly considered its properties.

Aluminum and copper alloys.—Aluminum differs materially from the usual brass-foundry alloys based on copper, because the latter, while being melted, must be protected against the oxidizing and sulphurous gases of the fuel, as it readily absorbs oxygen and sulphur, and is constantly tending to return to its former state as an oxide or a sulphide. The reactions that take place with oxygen and sulphur are the source of many of the porosity troubles of the brass-founder, and in time, while melting such metals, it becomes second nature for him to apply methods that have for their object the protection of the metal against these harmful elements.

It is not necessary to apply these methods to aluminum—in fact, they might result in harm. Thus, charcoal is used liberally on the surface of melted copper alloys, but charcoal is harmful on molten aluminum, because it increases the loss of aluminum, as the latter covers the charcoal with a film of metal, thus getting entangled with it, and eventually has to be skimmed off and partly lost. Aluminum has no particular affinity for sulphur, and if it had, the latter could never reduce oxide of aluminum; therefore, no reactions could take place resulting in the production of gases. While aluminum has a great affinity for oxygen, when molten at a low

temperature it is coated over with a tenacious film, and this protects the metal from further action of the atmosphere. On account of this behavior, aluminum can be melted with impunity in contact with the air in open kettles, like lead and tin alloys, though, of course, a higher temperature is required. In figure 45 is shown a tilting aluminum melting furnace suitable for this condition. It is made by the Campbell-Hausfeld Co. of Harrison, Ohio. It uses iron crucibles or kettles, is oil or gas-fired, and makes a very convenient melting unit for aluminum.

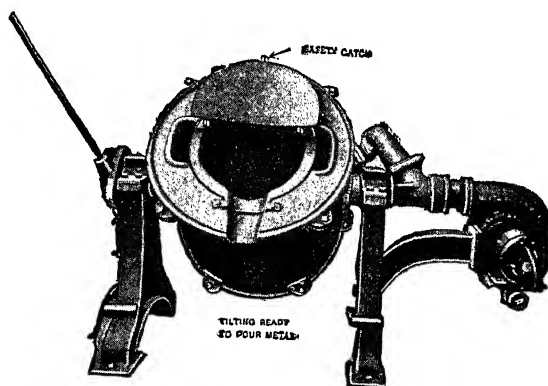


Figure 45.—Campbell-Hausfeld aluminum melting furnace.

When aluminum is melted in crucibles in closed furnaces, or in non-crucible furnaces, also necessarily closed, there is always danger of overheating the metal. In crucible melting, the pot is filled with solid aluminum, then may be left for a period according to experience, and while attending to other metals being melted, it may be forgotten until, on the furnace being opened, the aluminum will be molten and white hot. Then more solid metal is thrown in, and perhaps sufficient to solidify the contents of the crucible; then it passes through the same experience as before, and so on until the crucible is full. No other metal could be so treated, and still produce apparently good castings, so it is not to be wondered at that trouble is frequently experienced in making castings

of this metal. When melting aluminum in a crucible always use a deepener, as shown by the sectional view (figure 46) of a furnace. This attachment permits the charge being greatly increased, and also protects the tops of the ingots from the flame, which otherwise might melt them and so fall among the fuel.

For a detailed discussion of melting furnaces—pit, crucible, iron pot, open flame, reverberatory, and electric—see “Aluminum and Aluminum-Alloy Melting Furnaces” a paper presented before the June, 1922, meeting of the American Foundrymen’s Association at Rochester, N. Y., by R. J. Anderson.

Precautions in melting.—As quickly as the aluminum sinks down as it softens, and before it gets entirely liquid, further additions should be made, until the crucible is filled, when the furnace should be kept closed sufficiently long to allow the metal becoming entirely liquid and of a dark red color. At this stage the aluminum should be stirred, and about one ounce of zinc chloride thrown onto the surface, and stirred around as long as the reaction continues. This action will detach the aluminum from the dross with which it is always mixed, permitting the latter to be skimmed off as a powder. Some melters use sal-ammoniac (ammonium chloride), for the same purpose, but the zinc chloride is the best, as its melting point is low, about 690° F. Sodium chloride (common salt), is also used extensively when melting aluminum scrap for ingot purposes, but it is not to be recommended for foundry use as its melting point is 1280° F., and if it is heated considerably above this point, there is danger of overheating the aluminum, with the result of casting cracks.

Chemical activity of aluminum.—Aluminum is a very active element owing to its affinity for oxygen, an affinity which fortunately requires elevation of temperature above normal to bring it into activity. At a certain temperature it will take oxygen away from most elements containing it, and it is due to this affinity that aluminum can be used to reduce other metals from their compounds. All that is neces-

sary for this is to bring the aluminum into contact with the oxygen carrier, then heat a small portion of the mixture to the temperature necessary to start the reaction. Thus, in the case of copper oxide, the oxygen will be taken from the

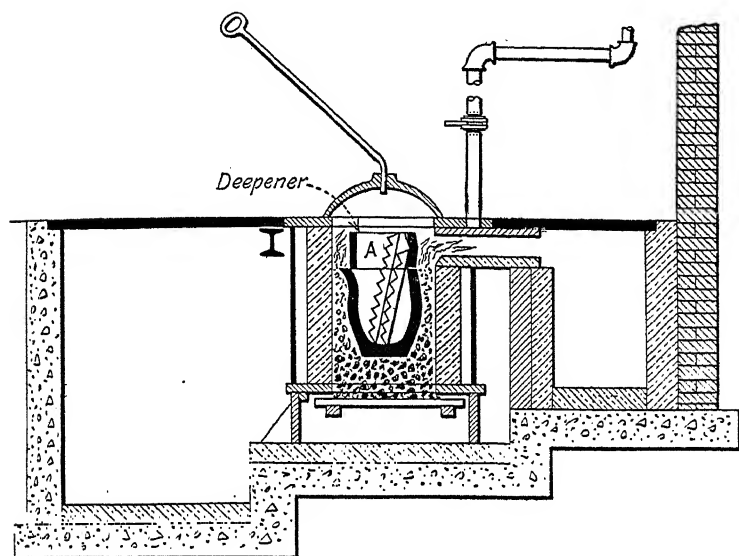
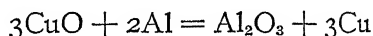


Figure 46.—Sectional view of furnace using crucible and deepener.

copper so suddenly that an explosion will result unless the oxide is in excess of the amount required by the equation:



which is about 82% copper oxide to 18% aluminum. But in these proportions the reaction is explosive, and the copper contains around 7% of aluminum, and it is necessary to mix the oxide and aluminum in proportions of 88% oxide and 12% aluminum. This quantity of aluminum will take the oxygen from over 7 times its weight of copper oxide. From sand or silica, aluminum will also take the oxygen, the result being an alloy of silicon and aluminum. Aluminum, according to Goldschmidt, will also react with charcoal, the air

entering into the reaction also, the product being aluminum oxide and nitride, and carbide (Al_4C_3).

Such a powerful element as aluminum should be handled with more respect than it gets in the average foundry, and every care should be exercised to keep its temperature, when molten, as low as consistent with a proper filling of the molds. When neglected while in a crucible, and overheated, aluminum will attack the silica in the walls and generate a high temperature at some point, resulting not so much in the absorption of silica, as, in a secondary reaction, due to the presence of the carbon in the crucible walls—which sets up a reaction as stated by Goldschmidt—resulting in the formation of oxide and nitride and the loss of aluminum; also the deterioration of that remaining molten by the entanglement of oxide.

Cracking of castings.—Such aluminum will crack more easily than properly melted and clean aluminum, and some of the mysterious troubles with the cracking of castings made from certain consignments of aluminum have been traced to overheating when the ingot was made from secondary metals. When pouring aluminum alloys, the temperature should be kept as low as possible and run the castings. When commencing a large order of aluminum castings it will always pay to spend time in determining the correct pouring temperature, after which use a pyrometer to ensure that every heat is poured at the proper temperature. A pyrometer can be used with great advantage in the case of the light alloys of aluminum.

In making test bars of aluminum alloys for tensile tests, it should be remembered that with such metals a normally rapid solidification is more important than a perfect feeding of the bar, so it follows that the methods used for copper alloys do not produce the best results with aluminum. It is important, in the case of copper alloys, that the test bars be gated, so there is a massive reservoir of liquid metal in a position to feed or seep down by gravity into the test bar and thus ensure the crystals being cemented together at all

points, instead of there being voids caused by a lack of eutectic between the crystals. This is more important than rapid cooling, hence we have the various forms of "fin" gates that are used in making such test bars. In the case of aluminum, the close proximity of a heavy feeding body of metal would so delay the cooling of the bar that its physical properties would greatly suffer. The proper place for feeding risers on aluminum cast-to-size bars is on the ends of the grips.

This peculiarity affects the disposition of test bars in the mold, when such bars must be cast attached to the castings. In the case of bronze, the test bar should be placed where it will be close to a heavy body of metal which will ensure soundness, with the result of the chances favoring a stronger test bar than casting. With aluminum alloys the reverse would be true. A test bar placed near the pouring sprue, in the case of a thin casting requiring fairly hot metal, would be much weaker than the casting itself, because it cooled more slowly, and many castings have been rejected because of this mistake. The strength of the casting was judged by the improperly poured test bar. The proper place for the test bar in such a case is as far from the pouring point as possible, and have the bar run properly. Thus, if the aluminum has to be poured hot to run the casting, let it flow through the casting first, then as it fills up a riser it will also fill the test bar rooted to both riser and casting. Such a bar will cool at the same time as the casting, in spite of its heavier section, and will afford a test that will represent the casting.

Aluminum bronze is governed by the same considerations as the light aluminum alloys, and the gating and risers of the test bars should be along the same lines and not follow those used in the case of the copper-tin and other alloys of copper.

ALLOYS OF ALUMINUM

In the United States, probably the alloys of aluminum most extensively used are those with copper, the favorite being known as No. 12. This alloy differs slightly in its

copper content when made from new metals, but the usual amount of copper introduced is 8%. The 8% alloy is a good ordinary aluminum alloy; it will have a tensile strength ranging from 18,000 to 20,000 lb. per sq. in. when properly made—that is, when the points mentioned early in this chapter are observed.

The physical properties of 92–8 aluminum (commercial)—copper alloy are as follows:

Physical properties of No. 12 alloy

Ultimate strength, lb. per sq. in.	16,000 to 20,000
Yield point between, lb. per sq. in.	11,000 to 13,000
Elongation, %	0.5 to 2.0
Reduction of area, %	0.5 to 2.0
Specific gravity at 20° C.	2.8
Brinell hardness number, using the 500 kilogram weight for 30 seconds.	50 to 55
Pattern maker's shrinkage allowance, inch per foot.	0.21
Weight, lb. per cu. in.	0.10
Compression, elastic limit, lb. per sq. in.	10,000
Modulus of elasticity, lb. per sq. in.	10,000,000

Modifications of the above No. 12 alloy may consist of either a reduction or an increase in the copper content, or the addition of other elements, such as iron, manganese, nickel, and zinc. The object of the modifications may be either to obtain an alloy that will be more ductile in the cold—as when the copper is reduced to 3, 4, or 5%—or to obtain an alloy of greater strength at elevated temperatures—as when the copper is increased to 9, 10, 10.5, and up to 14%—which results in an alloy less liable to crack during casting, and stronger than the lower copper alloys when used at temperatures considerably above normal. This can be shown by the following table of tests made in 1917 by the National Physical Laboratory in England, and presented by Ernest V. Pannell of the British Aluminum Co., in an article on “Aluminum Alloy Pistons” in *Metal Industry* of January, 1921.

All the alloys tested were made from metal cast in permanent molds, and they show why, for use as pistons of internal-combustion engines, it is necessary to employ alloys of high

copper content, and why alloys containing considerable zinc are of little value.

TABLE 18.—*Tensile strength of aluminum alloys at high temperatures*

Composition of alloys								Tensile strength at 350° C. (819° F.), lb. per sq. in.
Aluminum, %	Copper, %	Manganese, %	Magnesium, %	Nickel, %	Iron, %	Zinc, %	Tin, %	
83.00	14.00	1.00	None	None	.....	1.00	1.00	16,300
85.00	14.00	1.00	.....	.....	.....	.....	.....	14,300
84.00	14.00	.....	.....	2.00	.....	.....	.....	13,600
84.00	14.00	1.00	.....	.....	.....	.....	1.00	13,400
85.00	14.00	.....	.....	.....	1.00	.....	.....	12,000
86.00	14.00	.....	.....	.....	.....	.....	.....	10,700
88.00	12.00	.....	.....	.....	.....	.....	.....	10,300
86.00	12.00	.....	.....	2.00	.....	.....	.....	10,000
91.00	8.00	1.00	.....	.....	.....	.....	.....	9,700
92.50	4.00	.....	1.50	2.00	.....	.....	.....	9,640
92.00	8.00	.....	.....	.....	.....	.....	.....	7,500
91.00	7.00	.....	.....	.....	.....	1.00	1.00	6,950
94.00	6.00	.....	.....	.....	.....	.....	.....	6,900
83.00	2.00	.....	.....	.....	.....	15.00	.....	5,000

According to the investigations of the U. S. Bureau of Mines, which operates a non-ferrous laboratory, particularly aluminum, at Pittsburgh, Pa., in charge of R. J. Anderson, about 97% of all aluminum castings made in the United States consist of the so-called No. 12 alloy. The alloy can be obtained on the market, made from either new or secondary metals, or part new and part secondary metals. As the alloy is continually passing through the cycle—ingot, castings, scrap, and ingot—it picks up a certain amount of foreign elements, such as iron and zinc, which at first were considered very injurious to aluminum alloys, but which experience has shown to constitute an improvement of the casting qualities of the alloy when present within certain limits. Thus, some manufacturers of aluminum crank-cases, vacuum-cleaner housings, and similar castings, rather favor an alloy of 7.50% copper, 1.00 to 1.25% iron, and 1.50 to 2.00% (1.75% preferred) zinc. It is claimed that this composition has a much less tendency to crack in the sand; also that it is comparatively

easy to get a tensile strength running over 20,000 lb. per sq. in., with an elongation of 1.5 to 2.0%, physical properties that are obtained in the case of the straight No. 12 alloy only by very careful manipulation.

Cracks in castings.—The cracking of aluminum castings while cooling in the sand is annoying, expensive, and at times very mysterious. The latest literature on this subject is the paper "Cracks in Aluminium-Alloy Castings," presented by R. J. Anderson at the Feb., 1922, meeting of the American Institute of Mining and Metallurgical Engineers at New York. It is a singular thing that two alloys may be exactly alike in analysis, and both be molded and melted by the same men in the same foundry, yet one alloy in a day's run may produce 100% sound castings as far as cracks are concerned and the other alloy 100% of castings that are cracked, and so worthless. This refers, more particularly to re-melted material; and as a general rule, when the history of both alloys is unfolded, that of the one which cracked will be found to have been melted at a higher temperature than the good alloy when the scrap was re-melted for ingots.

It has been thought that the presence of alumina was responsible for this difference, and when trouble of this character is encountered, an analysis of both alloys, with particular reference to their alumina content might throw light on the problem. Aluminum oxide is heavier than aluminum, therefore it has a tendency to sink to the bottom of the furnace or melting vessel. In the case of crucibles used for melting aluminum, it will be observed that considerable dross will cake at the bottom and on the sides, so evidently the alumina has a tendency to "precipitate." But aluminum does not melt to a cleanly fluid body like some other metals; it is always viscous, because its molecules, although driven apart by the heat, have such an affinity for one another that the whole molten mass may be said to be in a condition like a piece of stretched rubber, with the result that a finely divided substance like its own oxide, only sinks very slowly and gradually, therefore some is held by the metal, and acting

like the parting of a mold, causes a separation of the metal when the strain of shrinkage comes upon it.

Some aluminum melters claim to drive out cracks by the addition of zinc, and keep the content of this metal close to 1.75%. Others regard zinc as harmful and the cause of cracks, and want a No. 12, zinc-free. Others again regard a small amount of manganese as being especially harmful in producing cracks, while others regard it as harmless—even beneficial. Many of these contrary opinions have been formed as a result of experience, and possibly originated in some difference in melting or molding practice in the respective shops where the results justified such opinions. However, when trouble from cracks is experienced, it will do no harm to try a heat with the addition of the small amount of zinc mentioned, provided that no zinc is present, for there are well authenticated cases where this addition has stopped such cracking.

When cracks persistently appear, the first steps should be to ascertain if the molds are being rammed harder than necessary; then the cores should come in for scrutiny, and then the gating. If the castings have been run before and came sound, the gates, if unchanged, may be omitted from the investigation; but if the castings are of new design, the gate can be given profitable study. In a foundry where the author of this volume was once employed, large orders were obtained for thin aluminum disks, somewhat like a flat wheel of intricate web design. The wheels were from 12 to 18 inches in diameter, and the molders gated them on the rim with two broad, flat gates branching from the sprue, and a small riser on the opposite diameter of the casting. Fully 95 per cent of the castings came cracked, sometimes in one place and sometimes in another. Day after day the result was the same although every experiment that could be thought of was tried in vain, until at last the gates were changed. Instead of the time-honored "frog" gate which had resulted so disastrously, the castings were run by means of a number of "pencil" gates—little upright risers, no thicker than a lead

pencil, disposed at regular intervals over the casting. On the back of the cope these gates were connected by a channel, and a rammed-up frame covered the mold and carried the sprue which communicated with the channel leading to the little pencil gates. This entirely stopped the cracks. At first a little lower output resulted from the change, but this was remedied by devising labor-saving conveniences especially applicable to the new methods. This incident shows that it is not always the composition of the alloy that is at fault, and in looking for a remedy for this distressing trouble nothing must be overlooked.

Another difficulty encountered in the case of alloys of aluminum is porosity, the presence of holes, which may appear as small specks distributed throughout the mass of the aluminum, or as larger, irregularly-shaped cavities not uniformly distributed, but collected in colonies at certain parts of the casting. Usually these defects are uncovered when the skin of the metal is removed during polishing, or machining operations.

The small, uniformly distributed holes frequently have their source in hot pouring of the alloy, and will disappear when the pouring temperature is lowered. In experiments carried out by the author, in molding a block 4 by 4 by 8 inches it was found that No. 12 aluminum alloy poured at 850° C. (1562° F.), made porous castings, but when poured at 680° C. (1256° F.), by pyrometer, the castings were free from holes. When the alloy was heated in the furnace to 900° C. (1652° F.), and cooled before pouring into the molds to a temperature of 680° C., no holes were visible. No holes could be seen in either case when the alloy was poured into iron molds which quickly chilled it. It appears probable, therefore, that these holes are caused by the dampness of the sand molds, and the theory was deduced that the heated aluminum has power to decompose the steam into its constituents—oxygen and hydrogen—and as the latter element is noted for the rapidity of its diffusion through metals, it was responsible for the holes, as these were not only found on the outside of the castings, just under the skin, but were dis-

tributed throughout, in the center as well as on the outside. Such penetration could be expected with hydrogen.

If the gas was hydrogen, it might be possible to de-hydrogenize the aluminum, and to this end additions of sulphur, selenium, and tellurium were made. One per cent of tellurium produced castings free from porosity when poured at 750° C., and also when poured at 900° C., but in the latter case the skin of the casting was badly discolored. These tests are mentioned in the hope that it will result in further and more careful investigation. Some aluminum founders claim that these holes can be eliminated by the addition of tin to the aluminum, and alloys containing 86% aluminum, 7% copper, and 7% tin, are in use. It is difficult to see how tin can influence the result. It is an established fact that the holes can be controlled by the pouring temperature of the castings.

The second class of holes are only found at certain parts of the castings, and it seems to be proved they are caused by entrapped air—that is, they are produced when holding the spout of the pouring vessel at a point above the mouth of the sprue with the result that air is caught by the stream and is carried into the mold, and is held there by the viscous metal until it has solidified. Cases are known where the difficulty has ceased to exist when the pouring vessel was held so that the lip touched the flask. These holes are also sometimes caused by shrinkage, and can be eliminated by using chills, or by placing gates and risers elsewhere.

Hardening alloys.—Alloys of copper and aluminum are conveniently made by the use of a hardener of 50-50 copper and aluminum. This alloy can be purchased ready made, or be made up in the foundry requiring it. This 50-50 hardener is simply charged with the ingot aluminum and both are melted together, then thoroughly stirred. As before mentioned, ingot of the composition of 90 to 92% aluminum, and 7 to 8% copper, with small amounts of other metals—not considered injurious—is a regular commercial alloy.

Aluminum-zinc-copper alloys.—An alloy of this composition is also used to some extent. It is cheaper than the No. 12, and could be used more frequently than it is. The con-

stituents of alloy 31, as it is known, is 81.50% aluminum, 15.00% zinc, 0.50% manganese, and 3.00% copper.

As a general rule, the manganese is omitted, and the alloy simply consists of 3% copper; 15% zinc; and the remainder aluminum. The physical properties of this alloy follow:

Physical properties of No. 31 alloy

Ultimate strength, lb. per sq. in.	20,000 to 26,000
Yield point, lb. per sq. in.	12,000 to 15,000
Elongation, % in 2 inches	1.0 to 3.0
Reduction of area, %	1.0 to 2.0
Specific gravity, at 20° C.	3.1
Brinell hardness number, using the 500 kilogram weight for 30 seconds	60 to 65
Patternmaker's allowance for shrinkage, inch per foot	0.186
Weight per cubic inch, lb.	0.11
Compression, elastic limit, lb. per sq. in.	12,000

Tests of aluminum alloys on the White-Souther endurance machine gave results as follows:

Analysis of alloys tested, per cent

	1	2	3	4	5
Aluminum	92.5	83.42	91.12	81.20	83.75
Zinc	None	16.24	None	15.20	16.24
Copper	7.84	0.34	8.86	3.06	None
Manganese	0.11	None	0.02	0.54	0.01
Specific gravity	2.84	2.97	2.88	3.08	2.94

The endurance of No. 1 alloy was 816,500 revolutions; of No. 2, 1,618,300 revolutions; of No. 3, 507,200 revolutions; of No. 4, 327,100 revolutions; and of No. 5, 980,800 revolutions.

A third aluminum alloy used to some extent is as follows: Aluminum, 65%, and zinc, 35%. The tensile strength of this alloy will often reach 35,000 lb. per sq. in. Its specific gravity is 3.30.

Other aluminum-zinc-copper alloys are the following:

No. 6		No. 7		No. 8	
	Pounds		Pounds		Pounds
Aluminum	73.50	Aluminum	90.00	Aluminum	93.00
Copper	3.50	Zinc	7.00	Zinc	5.00
Zinc	23.00	Copper	3.00	Copper	2.00

Tests made on cast-to-size bars molded in sand, risers on grips, and poured a few degrees under 700° C., show the following:

Properties of No. 6 alloy

Ultimate strength, two bars, lb. per sq. in.	33,900 and 35,600
Yield point, lb. per sq. in.	21,400 and 20,600
Elongation, % in 2 inches.	1.0 and 1.0
Reduction of area, %.....	1.2 and 1.6

Tests of No. 7 alloy averaged as follows: Ultimate strength, 13,400 lb. per sq. in; yield point, 11,100 lb. per sq. in.; elongation, 2.0% in 2 in.; and reduction of area, 2.8%.

How the strength of an aluminum alloy is increased by rapidly cooling from a molten state is illustrated by the following tests: About 100 lb. of an 8-92 copper-aluminum alloy was made from virgin metals, and was poured into molds composed of four different substances. The materials of the molds were molding sand, amorphous carbon, iron, and Acheson graphitic carbon. The molds were all made to produce an ingot about 8 inches long, 4 inches deep, 3 inches wide across the upper surface, and 2 inches wide at the bottom, with a taper from top to bottom, as is usual with brass ingots. The sand mold was poured first, then the amorphous carbon, then the iron (cast), then the graphite mold. The heat conductivity of each mold stepped up from sand to graphite. When the ingots were cool, longitudinal sections were cut from the bottoms of each, and turned into standard test bars, from which the following physical properties were determined:

	Graphite mold	Iron mold	Carbon mold	Sand mold
Ultimate strength, lb. per sq. in. .	26,300	25,500	17,700	12,300
Elongation, % in 2 inches.	3.8	3.5	1.8	1.0
Reduction, %.....	4.4	4.1	1.3	0.7

The low values for the sand-cast ingot must not be taken as a reflection on the quality of the alloy, as cast-to-size test bars of the same metal gave normal values for this alloy, but

they were due to the very slow cooling induced by the mass of metal in the sand mold. All molds were cast with tops open to the air. It was observed that the alloy cast in the sand mold remained liquid for a considerable period after the other ingots had solidified. The amorphous carbon remained liquid for some time after the graphite ingot and the iron ingot had solidified. The graphite and iron set about the same time, due no doubt to the fact that the iron mold was poured before the graphite mold. Thus the ingots solidified in the order of their heat conductivities, and the tests prove this.

Pouring temperatures of aluminum alloys.—The melting point of aluminum is 658°C . (1216°F .). For heavy castings, a pouring temperature of 680°C . (1256°F .) will be satisfactory, giving the metal a little over 40°F ., of superheat, as most alloys will melt at a lower temperature than aluminum itself. Thinner castings will require a little more superheat, and 700°C . (1292°F .) will give 76° of superheat. Very thin castings may require more heat still, but a temperature of 720°C . (1328°F .) should run any foundry alloy. The temperatures should be determined by a pyrometer, as this is quite feasible with aluminum alloys. When a pyrometer is not at hand, the temperature can be judged by the color of the metal, although this method is not as reliable as it should be. When the metal looks silvery-white, its temperature will be a little under 680°C ., while at about 720°C . it will be a dark red.

The temperature at which aluminum is poured into the mold has a great influence on the quality of the casting. This is another different characteristic when compared with ordinary foundry metals, such as brass or iron. If the latter metals are poured hotter than strictly necessary, the castings may be rougher, but they are not greatly impaired in their physical properties. In the case of aluminum, as shown by the tests in different heat-conducting molds, it makes a great difference in the physical properties, for if poured hot it will cool more slowly. The tendency to form cracks is increased by the increased temperature of pouring, and if the metal

thickness can be so regulated that the castings run perfectly at the upper limit of 720° C., better results will be attained.

British aluminum alloys.—The tendency in Great Britain appears to be to use alloys containing zinc. The British equivalent to No. 12 alloy is one containing from 2 to 3% copper, 8 to 10% zinc, and the remainder aluminum. For castings to contain fresh water an alloy of 10% copper and 90% aluminum is much used. A zinc alloy very favorably regarded contains 20% zinc, 3% copper, and aluminum the remainder. Sometimes the zinc content is raised to 25%. The alloys used for pistons are: Air Board Specification, L 8, 88% aluminum, and 12% copper; Air Board Specification, 2. L11, 92% aluminum, 7% copper, and 1% tin; and Air Board Specification, L10, 89% aluminum, 10% copper, and 1% tin. An alloy known as L5 contains from 2.5 to 3.0% copper, 12 to 14% zinc, and the remainder aluminum. An alloy containing 84% aluminum, 13.25% zinc, and 2.75% copper, is claimed to possess a tensile strength of 12 to 14 tons (26,880 to 31,360 lb.) per square inch, a yield point of 8 tons (17,920 lb.), and an elongation of 6 to 7%.

One of the most complete investigations of aluminum alloys ever undertaken is that known as the 11th Report of the Light Alloys Research Committee of the Institution of Mechanical Engineers. This research was the result of the organized work of practically the whole staff of the Metallurgical Department of the National Physical Laboratory, and was presented to the Institute by Walter Rosenhain, Sydney L. Archbutt, and D. Hanson, of the National Physical Laboratory, Teddington, England.

Copper-zinc-aluminum alloys.—Cast alloys, made both in sand and chill molds, were investigated, using alloys containing 2 to 3% copper and from 25 to 35% zinc at first. These showed tensile strengths of as high as 42,500 lb. in sand castings and 44,800 lb. in chill castings. The 15% zinc alloys dropped in tensile to 31,300 lb. maximum. As alloys with high zinc are weak and brittle when hot, and are thus liable to cracking in the foundry, a better all round alloy is obtained

with lower zinc, and an alloy such as "L5" containing zinc, 12.5 to 14.4%; copper, 2.5 to 3.0%; and aluminum the remainder, which in chill bars may have 11 tons (24,640 lb.) per square inch tensile strength, with 4% elongation, is more extensively used. This alloy also gets stronger with age, and its density is approximately 3.0.

The strength of alloys at higher temperatures than normal was also investigated. Thus the L5 alloy may have a tensile strength of 13.5 tons (30,240 lb.) per square inch, at normal temperatures, but when it is heated to 250° C. (482° F.), this falls off to about 4 tons (8960 lb.); and at 350° C. (662° F.), to 1.5 tons (3360 lb.). This shows that alloys containing zinc are unsuited for the heated parts of internal-combustion engines.

Copper-aluminum alloys.—The copper-aluminum alloys act much better at high temperatures; thus, when they contain from 6 to 14% of copper, the strength at 250° C. (480° F.), is around 7 tons (15,680 lb.) per square inch, and the 12% copper alloy at 350° C. (662° F.), has a tensile strength of 4.6 tons (10,304 lb.) as compared with only 3.4 tons (7617 lb.) of an alloy of 8% copper. The 12% copper alloy is the best of the binary copper-aluminum series to use for pistons, and is known as Air Board Specification L8.

Manganese was found to increase the strength of such alloys at all temperatures, and the best proportion to use was discovered to be 1%, as this increases the tensile strength of both the 8% and the 14% copper-aluminum alloy about 2000 lb. per sq. in. at normal temperatures; and as this increased strength is retained both at 250 and 350° C., an alloy of 14% copper, 1% manganese, and 85% aluminum is an improvement over the strictly copper-aluminum series.

Other elements investigated in connection with the copper-aluminum series of alloys were tungsten, molybdenum, iron, vanadium, and chromium, but no better results were obtained with these additions to aluminum alloys containing copper as the hardener. Nickel, however, was found to be beneficial, as it increased the strength of the copper-aluminum

alloys, both when cold and heated to 250° C.; and the further addition of magnesium to the copper-nickel-aluminum alloys was an improvement.

When both nickel and magnesium are present, it was found that the copper could be reduced—which would be expected. This led to the testing of an alloy containing 4% of copper; 2% of nickel, and 1.5% of magnesium, and this product was named "Y" alloy. When cast in one-inch bars in chills, this alloy has a tensile strength of 13 tons (29,120 lb.) per square inch when cold; and about 11 tons (24,640 lb.) at 250° C. (480° F.), 8 tons (17,920 lb.) at 300° C. (572° F.), and 5 tons (11,200 lb.) at 350° C. (662° F.). The elongation of this is stated to be fairly large, namely, 15% (with chill cast bars), so the alloy can be worked by rolling and forging.

Effect of heat-treatment.—It has been found that heat-treating aluminum alloys improves most of them, as practically all possess inequalities of composition due to micro-segregation during solidification. Thus in the case of alloys containing as little as 2% of copper, free particles of the compound CuAl_2 are normally found; whereas a saturated solid solution of this compound in aluminum contains nearly 5% of copper. This undissolved CuAl_2 , when annealed at 500° C. (932° F.), is brought into solid solution in alloys containing up to about 4.5% of copper, and this increases the strength from 8 tons as cast, to 10 tons after the anneal, in the case of the 2% copper alloy; and if 4.5% copper is contained in the aluminum, its strength is increased by heat-treatment from 9.5 to 15 tons per square inch. The elongation is also materially increased.

Improvement by ageing.—The alloy "L 5" has been found to increase in strength about 30% during the first 10 months after casting, and a similar improvement occurs in the case of an alloy containing 3% copper, 15% zinc, and remainder aluminum. This change is known as "ageing," or "maturing" which has been suggested as a better term for this phenomenon.

Some aluminum alloys after being worked are as sus-

ceptible to "season cracking" as brass. An alloy of 2.5% copper, 20% zinc, and 0.5% magnesium and manganese, both with and without 0.75% of silicon, is peculiarly liable to season cracking. Microscopic examination showed that failure of this kind is associated with a completely equiaxed microstructure, accompanied by smooth, regular crystal boundaries. The 11th Report also mentioned the thermal conductivity, permanence, stability of dimensions, and other properties of the alloys examined.

An alloy specified for pistons by a large automobile builder in Great Britain is copper, 4.5 to 6%; nickel, 0.5 to 0.80%; zinc, 1.20%; antimony, 0.7 to 1.0%; and aluminum, 91%. An alloy (British patent No. 132,984, Oct. 2, 1919) for resisting pressure contains aluminum, 100 parts; lead, 5 to 15 parts; bismuth, 3 to 8 parts; and up to 4 parts of tin.

U. S. Navy Specification, 49-A-1.—This alloy is specified as follows: Aluminum, 94%; copper, 6%; iron, 0.5%; silicon, 0.5%; and manganese, up to 3%. The physical properties demanded are: tensile, 18,000 lb. minimum; and elongation in 2 inches, 8% minimum.

Copper-manganese-aluminum alloys.—The specifications allow a sufficiently wide margin in the copper and manganese contents to permit the required physical properties to be realized. The percentages of both copper and manganese have to be lowered considerably to get 8% elongation. The alloy is a difficult one to run into castings as it is quite viscous or "mushy," and castings are very liable to be filled with holes under the skin. Molds for heavy castings must be well nailed with round-headed nails of large size which act as chills. In addition, heavy feeders, and in some cases sillage heads, are needed for chilling to ensure sound castings. Alloys of copper, manganese, and aluminum appear to have been first described by P. E. McKinney in a paper presented before the American Institute of Metals at the Tenth Annual Convention, and incorporated in the Transactions of the Society (Vol. X, 1916, pages 166 to 178). Some of the tests given by Mr. McKinney are as under, the composition of the alloy tested

being manganese, 1.50%; copper, 2.00%; and aluminum, 96%:

Tests on a manganese-copper-aluminum alloy

Alloy No.	Tensile strength, lb. per sq. in.	Elongation in 2 inches, %
1	22,000	15.0
2	22,000	14.0
3	21,000	8.0
4	19,000	9.5
5	19,000	14.7
6	19,000	14.0
7	21,000	13.0
8	22,000	12.0
9	24,000	10.0
10	19,000	12.0
11	18,000	13.0

The elastic ratio of the alloy as determined by the drop of the beam of the testing machine will average about 60% of ultimate strength. The fracture of test specimens is silky and shows considerable toughness, instead of being granular and brittle, as is the case with many aluminum alloys.

Forging alloys.—These alloys are very suitable for forging, and McKinney stated that the same type of ingot molds as used for bronze forging ingots are suitable for aluminum. The molds are heated to about 500° F., and are given a thin coating of orange shellac to produce a clean skin. The metal should be carefully skimmed and poured quickly to avoid "cold shots" caused by the low temperature at which it must be poured. The experience of the author of this volume with this alloy has been to the effect that the same method must be adopted in the case of sand molds, namely, low temperature pouring and strong pouring, also gating from the bottom of the mold.

In making drop forgings, a little preliminary forging is very desirable, according to McKinney. The ingot can be cut or cropped to the desired lengths, and forged to approximate shape at a temperature of from 1000 to 1150° F., after which they can be finished in dies. These alloys flow with ease during forging, and have been found to fill the dies

well in all cases. Forging dies of the same type as used for tobin bronze are perfectly satisfactory for aluminum work.

The stiffness and strength of the forged material can be controlled by varying the finishing temperature. Considerable stiffness and elasticity can be imparted to the forgings by two or three blows of the forging dies, at about 500° F.

The following are typical physical properties obtained on bars of this alloy, forged to one inch square, and turned to standard size tensile specimens:

1. A soft alloy containing 1.00% manganese, 2.00% copper, and 96.50% aluminum.

Condition	Tensile strength, lb. per sq. in.	Yield point, lb. per sq. in.	Elongation in 2 inches, %	Reduction of area, %
Cold finished.....	27,750	27,750	12.0	47.0
Hot finished.....	21,083	12,223	26.7	48.7
Intermediate.....	25,617	22,918	17.4	52.0

2. A hard alloy containing 2.00% manganese, 3.00% copper, and 94.50% aluminum:

Condition	Tensile strength, lb. per sq. in.	Yield point, lb. per sq. in.	Elongation in 2 inches, %	Reduction of area, %
Cold finished.....	31,930	30,000	9.75	35.3
Cold finished.....	34,123	33,000	4.00	11.25
Cold finished.....	30,405	30,000	11.25	30.78
Hot finished.....	27,450	15,000	21.95	56.00
Intermediate.....	28,670	22,000	21.00	50.40

The increased density produced by forging makes the alloy a great deal more resistant to corrosion by sea water than the cast alloy, and some very promising reports on service tests made on ships at sea to determine resistance to corrosion have been received by the U. S. Navy Department.

Aluminum alloys for cooking utensils.—An alloy extensively used for cast cooking utensils consists of 97% aluminum, and 3% copper. Some authorities contend that such alloys are unsuited for the purpose, and that neither copper nor

zinc should be contained in such alloys, because it is claimed that copper will cause the aluminum to pit, and zinc will cause discoloration. A zinc-copper-aluminum both pits and discolors, and even a slight quantity of copper gives rise to pitting. Virgin aluminum, grade A, only should be used, is the claim of these authorities.

Unalloyed aluminum in a cast condition would be too soft, and some element would have to be added to stiffen it, also to take away its "clinging" nature which makes it difficult to finish. For this purpose magnesium can be used, plus possibly a little manganese, when considered desirable to eliminate copper and zinc. Alloys of aluminum, nickel, and magnesium, would also avoid the use of copper and zinc.

MISCELLANEOUS ALLOYS

Alloys for crank-cases.—(1) Aluminum, 91.00%; copper, 8.00%; and iron, 1.00%. (2) Aluminum, 90.00%; copper, 7.00%; iron, 1.25%; and zinc, 1.75%. (3) Aluminum, 90.25%; copper, 8.00%; and iron, 1.75%.

Vacuum cleaner housings.—Alloys used on crank-cases, and alloys with up to 10% copper.

Aluminum and beryllium.—Alloys of aluminum and beryllium have been patented by F. A. Fahrenwald (U. S. patent, 1,333,965), and are described as light and strong, suitable for use in the manufacture of airplane parts. An alloy of 90% aluminum and 10% beryllium is mentioned; also one of 85% aluminum, 10% beryllium, and 5% copper.

Zeppelin and airplane alloys:

TABLE 19.—Analyses of alloys used in German Zeppelins

Part	Al, %	Zn, %	Mg, %	Fe, %	Si, %	Cu, %	Sn, %	Mn, %	Ni, %
Angle brackets....	90.27	7.80	.....	0.45	0.37	0.73	0.11	0.27	Trace
Channel sections...	88.68	9.10	.....	0.43	0.49	0.70	0.15	0.43	"
Braces.....	99.07	0.13	.....	0.38	0.36	0.06	.....	.....	"
Pistons in a 1918 German airplane.	80.12	12.13	Trace	1.42	0.31	6.02	.....	Trace	

Duralumin.—The composition of this alloy may vary slightly. One analysis by J. L. Jones of the Westinghouse Electric & Mfg. Co. gave the following proportions: aluminum, 94.60%; copper, 3.90%; iron, 0.45%; magnesium, 0.75%; silicon, 0.21%, and manganese, a trace. In a paper by P. D. Merica, R. G. Waltenberg, and H. Scott, presented before the Institute of Metals section of the American Institute of Mining and Metallurgical Engineers, the composition of duralumin is placed within the following limits: copper, 3 to 4.5%; magnesium, 0.4 to 1.0%; manganese, 0 to 0.7%; aluminum, remainder; iron (as impurities), 0.4 to 1.0%; silicon, 0.3 to 1.0%. Its density is given as about 2.85. It is used only in the forged or rolled condition.

Alpax.—This is an aluminum-silicon alloy invented and patented by Aladar Pacz, after whom it was named. It is a fine-grained, ductile alloy containing about 87% aluminum and 13% silicon, and is distinguished by a low linear contraction. It is usually made by the addition of a rich alloy of silicon and aluminum (50-50) to ingot aluminum. A modification of the alloy is known as "aluminac," and is used for making die castings of aluminum alloy. The silicon-aluminum alloys are difficult to machine, as they tear and cling to the tools, so adding copper has been tried and found to impart better machining qualities.

Aerolite.—This is a light aluminum alloy having the following composition by analysis: Aluminum, 96.93%; zinc, 0.12%; silicon, 0.45%; iron, 0.97%; copper, 1.15%; magnesium, 0.38%. Its specific gravity is 2.74.

Aerolite should be put together by means of a hardener, which adds all the metals comprising the alloy, except the magnesium. When so made by the author of this volume, the following physical properties were realized with cast-to-size standard test bars, made in green sand molds.

Tensile strength, lb. per sq. in.....	28,700
Yield point, lb. per sq. in.....	13,600
Elongation, % in 2 inches.....	4.0
Reduction of area, %.....	5.0

Aluminum pattern alloy.—Aluminum, 90.00%; copper, %; and tin, 2.00%.

Aluminum piston alloys.—The following alloys were outlined by Ernest V. Pannell, in a paper published in *Metal Industry* of January, 1921:

TABLE 20.—Composition and properties of aluminum piston rings

Name	Al, %	Cu, %	Sn, %	Zn, %	Mg, %	Mn, %	Fe, %	Elongation, %	Specific gravity	Tensile strength, lb.
Corbin....	87.50	12.50	....	....	....	....	....	....	2.95	22,000
Belgian....	90.50	7.00	....	2.50	....	....	....	....	2.87	....
Curtiss....	95.20	2.50	....	1.50	....	....	....	2.00	....	28,000
Aerolite....	86.00	12.00	....	....	....	2.00	....	....	....	22,000
Air Board..	89.00	10.00	1.00	....	....	....	....	....	....	20,000
Air Board..	88.00	12.00	....	....	....	....	....	....	2.89	22,000
Air Board..	85.00	14.00	....	....	....	1.00	....	....	....	....
Benz										
Aviatik..	80.00	6.00	....	12.00	....	....	1.50	....	....	....
German..	93.00	....	....	....	7.00*	....	....	6.0	2.50	27,000

* Magnalium.

Magnalite.—Aluminum, 94.20%; copper, 2.50%; zinc, 0.5%; magnesium, 1.30%; and nickel, 1.50%; specific gravity, 2.8; tensile strength, 26,000 lb.; elongation, 2.5%.

Magnalium.—Aluminum, 95.00%; and magnesium, 5.00%; tensile strength, 22,000 lb.; elongation, 4.00%.

N. P. L.—Aluminum, 92.50%; magnesium, 1.50%; and nickel, 2.00%; tensile strength, 30,000 lb.; elongation, 2.00%.

Lynite No. 122.—Aluminum, 88.00%; copper, 10.00%; magnesium, 0.25%; and iron, 1.50%; specific gravity, 2.95; tensile strength, 28,000 lb.

Heat-treatment of aluminum-alloy castings.—This treatment was first applied to rolled or extruded aluminum of the alloy known as duralumin, consisting of 94.50% aluminum, 4.00% copper, 0.50% magnesium, and 1% manganese. Castings of aluminum being of a more porous nature than sheet have to be treated rather differently, and the process as described by Zay Jeffries and W. A. Gibson in a paper before the American Institute of Mining and Metallurgical Engineers,

at the Philadelphia meeting in September, 1919, consists in heating the castings in a fused bath of sodium nitrate and potassium nitrate for about one hour at a temperature of 520° C. or thereabouts, then quenching for an hour in boiling water, or in oil at a temperature of 100° . The physical properties of aluminum alloys are considerably improved by this treatment, especially of such alloys as contain magnesium.

CHAPTER VIII

ALUMINUM BRONZE

THE first conception of aluminum bronze was that of an alloy of copper and aluminum only, which must contain the least possible amount of impurities. According to some investigators, great attention should be given to the quality of the copper, as such impurities as arsenic, antimony, and iron, seriously affect the quality of the bronze. The aluminum bronzes were supposed to be peculiarly sensitive to these elements, especially to iron.

Effect of impurities, and the effect of iron.—Modern research has shown that while arsenic, phosphorus, and antimony are injurious, iron is very beneficial, more so than any other element. On account of the injurious effects of the first three mentioned, secondary re-melted copper is not safe to use in making the bronze; but electrolytic copper will be found the most economical in the end, because of difficulties avoided, which, if encountered, would mean loss of productive capacity. The other alloying element, aluminum, usually contains small quantities of both iron and silicon. The iron is not injurious, but its percentage should be known; but the silicon is harmful when present in quantity. About 0.1% of silicon will react on the elongation of the bronze in a very deleterious manner, though not to the same extent in ferro-aluminum bronze as in the binary alloy of aluminum and copper. In this binary alloy, silicon can be regarded as very harmful, therefore, scrap aluminum which may contain fairly large quantities of silicon from the re-melting of silicon-aluminum alloys, should never be used. Ordinary commercial aluminum will be satisfactory. The theory that iron was harmful to aluminum bronze has probably retarded the dis-

covery and consequent utilization of these valuable alloys, and has stood in the way of the commercial development of aluminum bronze for many years. The idea, no doubt, was largely based on the prejudice of all brass founders against iron, a prejudice in the case of the majority of alloys being well founded, and is due to the fact that iron fails to remain in solution with the copper-tin series of alloys, or with copper, zinc, tin, and lead mixtures, but segregates in the form of intensely hard nodules of steel.

It is probable that this segregation of iron in certain copper alloys is due to the absorption of carbon by the iron, and to the fact that it is too tightly held to be easily separated therefrom. Copper has no such affinity for carbon as is possessed by iron and some other metals—nickel, for instance—therefore it is unable to assimilate the combination of iron and carbon, and possesses no power to break them up into their constituents, combining with the one and rejecting the other. The result is that iron carbide, having no affinity for the copper or alloy of copper, and a much higher melting point, separates as small pellets scattered throughout the brass, causing much trouble for the machinist.

When the iron is carbon free, it will alloy with the copper at the proper temperature. Thus, in making alloys of iron and copper alone it is essential to use iron as free from carbon as possible, and also to protect the iron from carbon while melting. Copper and cast iron melted together and stirred—no matter how vigorously—will separate upon solidification. The evidence, therefore, points to carbon as the disturbing element in making alloys of copper and iron, and as carbon is always present in brass-foundry melting operations, if brass chips are melted, for instance, and the iron is not removed before the operation, it has an excellent opportunity to combine with carbon and it must be expected that nodules will be found in the castings.

Alloying power of aluminum.—Aluminum is an element which freely alloys with copper in all proportions; it will also alloy with iron, and when it is added to a liquid mixture of

iron and copper it will cause the two to combine, regardless of the presence of carbon. It is immaterial whether wrought or cast iron be used in making aluminum bronzes containing iron, because after the aluminum has been added, the carbon will be ejected from the iron. Wrought iron is probably more generally convenient to use than cast iron, because little, if any, allowance may be made for loss due to ejected impurities. When cast iron is used, the carbon is ejected by the aluminum, and floats to the surface of the molten alloy as a finely divided, flocculent mass, which can be skimmed off the metal, when it is necessary to use more iron to make up for this loss. In some instances where the furnace temperature is low it becomes more convenient to use cast iron in making alloys of copper and aluminum containing considerable percentages of iron. The cast iron and copper are melted together with due allowance for loss of weight by elimination of carbon, and the aluminum is added in small pieces. After each addition, a certain amount of carbon is ejected from the mixture; at first large masses will float up, and if the metal is skimmed after each addition of aluminum, it will be observed that the quantity of ejected carbon grows progressively less, until all is eliminated. There appears to be a definite ratio between the weight of the cast iron and the amount of aluminum necessary to eliminate the carbon.

Cast iron in aluminum bronze.—In several experiments made by the writer it appeared that if 20% of cast iron was melted with 65% of copper, it would require 15% of aluminum to eliminate the carbon and produce an homogenous alloy of copper, iron, and aluminum. There are many interesting features connected with the elimination of carbon from cast iron by means of aluminum and copper, which will not be discussed further than to observe that it affords a fertile field for research.

As aluminum promotes the alloying action of iron and copper, causing the former to go into solution, the difficulties met with in forming alloys of copper, tin, and iron, or of copper, zinc, and iron, do not exist in alloying copper, alumi-

num, and iron. The alloys are easily made, and when machined, appear to be free from the segregation of iron. The objections, therefore, that apply to the use of iron in ordinary brass or bronze, do not apply to aluminum bronze, so there is no good reason why these elements should not be alloyed together if it is found advantageous to do so. Regarding this point there is now no dispute. The physical properties of the bronze are improved by only small additions of iron, while larger amounts effect such greater improvements that an entirely new and greatly superior class of alloys has been evolved, some of which are being utilized with great success in the manufacture of the larger airplanes.

The discovery that iron was a valuable addition to aluminum bronze appears to have been made in Germany, but it is doubtful whether it was fully realized that it was the iron which was responsible for the improved properties of the alloys, because the iron was introduced as a constituent of a hardener containing several other elements, and it would be difficult to trace the improved properties to any one of its constituents. The German method differs materially from the American method, as devised by the author; and in passing it may be remarked that in all cases where the two methods have been tried side by side, the American method has prevailed, with the result that the foreign method was discarded by that manufacturer. The history of the discovery of ferro-aluminum bronze is too lengthy to relate here, but suffice it to say it was accidentally discovered by the author, assisted by Zeno D. Barnes, while working on an alloy for removing gases from aluminum bronze, which was so sensitive to iron that the merest trace would cause the well-known "worm holes" to appear in the castings. It was realized that the de-gasifier must be modified to permit of small amounts of iron in the bronze, and after this was accomplished, naturally the tests with iron followed, first, to determine to what extent iron was harmful, and then to determine just how iron should be used to realize its advantages to the full.

Vickers' patent.—A patent (U. S. patent, 1,264,459) for ferro-aluminum bronze was issued to Charles Vickers on April 30, 1918. It specifies an alloy containing not more than 12% nor less than 7% aluminum and not more than 5% nor less than 3% of iron, the proportions of aluminum to iron being not more than $2\frac{1}{2}\%$. Considerable publicity was given to these alloys by various writers familiar with the work going on, and some of the alloys came into use under different names. Thus there was "Sillman" bronze,

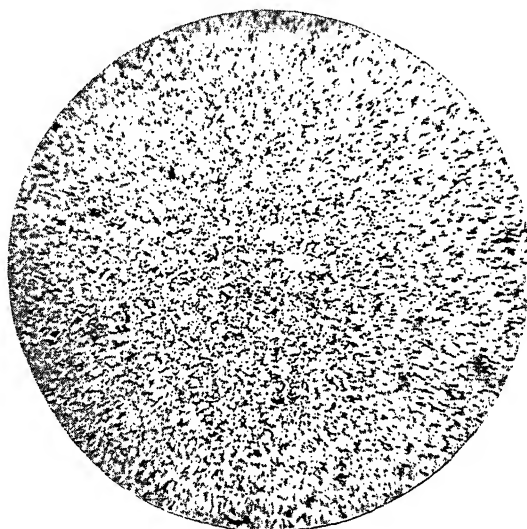


Figure 47.—Bronze ($\times 20$) consisting of 10% aluminum, 4% iron, and 86% copper.

which was tested by the U. S. Bureau of Standards under that name. The analysis of this latter alloy was: copper, 86.4%; aluminum, 9.7%; and iron, 3.9%. Its physical properties were found by the Bureau to be: tensile strength, cast, 78,850 lb.; elastic limit, 11,500 lb.; and elongation, 14.5% in 2 inches. Naturally, as in all cases of published new alloys, a very important part of the alloy was missing. Properly put together this alloy should have over 90,000 lb. tensile, with an elongation between 20 and 30. During the War it was used extensively for airplane parts, to connect the various

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parts of a plane built of high-grade steel tubing. The bronze castings were of peculiar form, on the order of the forgings used to connect bicycle frames. The strength of the bronze parts will be realized by the fact of a 90-ft. wing-spread plane being pulled out of the sea, into which it had fallen, by a derrick hitched to the tail. The frame of the machine was intact. The structure of this bronze is shown by the micro-photograph on figure 47.

Variation of elongation.—The elongation of aluminum bronze varies greatly, and may be from 18 to 40% in well-made alloys. The following results are interesting as being typical of what may be expected in ordinary practice:

Variation of elongation in aluminum bronze

No. of bar	Elastic limit, lb. per sq. in.	Tensile strength, lb. per sq. in.	Elongation, in 2 inches, %
1	27,410	55,510	4
2	22,560	55,900	8
3	24,730	37,720	10.5
4	20,610	59,900	17.0
5	19,690	53,700	3.5
6	23,170	40,410	11.5
7	20,870	47,870	5.0
8	21,570	42,800	6.0
9	20,167	48,270	11.0
10	19,720	45,670	4.5
11	20,680	54,150	5.5
12	23,120	58,500	2.0

The cause of the low physical properties of the above alloys was probably some little impurity in the copper, such as arsenic. It is easy to get such poor results, far more easy than to get the higher results, and these, as before remarked, never approach 100,000 lb. tensile in the case of the straight 10% aluminum alloy.

Strength of aluminum bronze.—A great amount of misrepresentation has been made regarding the physical properties of aluminum bronze: One authority states that the 10% bronze has a tenacity of about 100,000 lb., and a compressive strength of 130,000 lb., while its ductility and toughness are such that it does not even crack when distorted by

this load; and to quote, "It is so ductile and malleable, that it can be drawn down under a hammer to the fineness of a cambric needle. It works well, casts well, holds a fine surface under the tool, and when exposed to the weather, it is in every respect one of the best bronzes known." As a matter of fact, the strength and ductility of the binary alloy of aluminum and copper containing 10% aluminum is a very uncertain thing, as it is dependent upon so many variables. When made under the most favorable circumstances and with the utmost care, however, the tensile strength will rarely reach 70,000 lb. per sq. in., and can be considered as a well-made alloy if it is 60,000 lb. or so.

Casting troubles.—The good casting quality of bronze only applies to its fluidity; it will run into the molds and fill them well, in fact, better than the other alloys of copper, but it is the most difficult alloy to convert into castings that the founder has ever had to encounter. This has been the cause of the loss of large sums of money in the past, and is the cause of much hesitancy on the part of founders to cast the alloy at the present time. The alloy drosses badly, the castings shrink, and when these difficulties are overcome, and good castings are sent out, many instances are known where on being cut into, cavities have been opened up inside the casting, which have resulted in their being relegated to the scrap heap.

Another difficulty little realized lies in the fact that heavy castings of the 10% aluminum bronze are so affected by the slow cooling incident to their massiveness that their physical properties are invariably disappointing. In the small castings, the alloy cools quickly, with the result that the crystals are well-defined as shown by fractured surfaces. The larger and more slowly cooled castings possess a fracture inclined to the vitreous; the crystals have blended and merged, and show only as shadowy outlines on the fractured surfaces. Owing to this peculiarity, aluminum bronze containing 10% and over of aluminum, and no iron is not suitable for heavy castings to be employed in places where great strength is

required, unless the sections have been designed with a full understanding of the effects of slow cooling upon the alloy. It would be extremely dangerous to design a casting to be made of this alloy from data as to physical strength obtained from the testing of cast-to-size test bars, poured in molds separate from the casting. The results in this case would be entirely too high, and not at all in accord with the strength of the casting, even if the test bars were poured from the same heat of metal as the large casting. The cause of this disparity is the rate at which the two castings were cooled from the liquid state. The change produced by gradual cooling has been termed "self-annealing," by the author, but it is doubtful if the term fits the case exactly. The introduction of a small amount of iron into the bronze does not materially affect this tendency of the crystals to become blended by slow cooling; it is necessary to add a considerable amount of iron to accomplish this result. In the case of small castings, self-annealing effects can be reproduced by removing them from the molds red hot and introducing them into a heated muffle, where they are permitted to cool gradually to room temperature. By this treatment, small castings of aluminum bronze have been rendered so brittle as to be easily broken with a hammer.

When chilling is resorted to, self-annealing is prevented, because the casting is quickly solidified; but chilling is difficult and sometimes impossible to apply to heavy castings. If the castings are water-cooled from a red heat, they are hardened to a point where they become machinable with difficulty, as the bronze can be hardened like steel, but differing in degree. When the bronze is so hardened it loses its ductility to a great extent, although its tensile strength is increased; therefore, water-cooling of large castings if resorted to at all, must be carried out with a full knowledge of what it is sought to avoid—on the one hand, excessive hardness and brittleness, and on the other, normal hardness, but loss of both tensile strength and elongation. A massive casting, stripped from the mold and air-cooled, will of course be better in physical

properties than if left to cool in the mold, because it will cool more rapidly; but it will still cool too slowly to possess the properties indicated by the separately cast tensile test bars.

A number of careful experiments made by the author have shown the alloy to possess such sensitiveness in the matter of time of cooling, that the disposition of the feeding risers on the test bars is a matter of considerable importance in the way of getting the highest physical strength. In this respect the alloy resembles aluminum, and differs from the copper-tin alloys. In the latter alloys, rate of cooling is secondary to soundness, and soundness can be obtained in a test bar by attaching it to a heavy mass of metal as a feeder.

Making test bars.—Test bar and feeder should be laid parallel in the mold and the two connected by a rather heavy gate extending the entire length of the test bar. Under such conditions the cooling of the bar is retarded by the mass of metal lying alongside, and to which it is connected. This mass of metal ensures soundness in the test bar, and in the case of the copper-tin alloys, the highest physical properties of the alloy are realized by this treatment. In the case of aluminum bronze, the slow cooling induced by the mass of metal in the feeder outweighs any consideration of soundness; therefore, although the test bar would be sound, its physical properties would be lower than those of another bar cast from the same heat and cooled more rapidly, even if the latter had a slight unsound spot in its center. To get the best results from test bars of aluminum bronze it is necessary to attach the feeders to either end of the grips, so that the center will cool rapidly. In all cases, therefore, where it is important that the physical properties of aluminum bronze be known, the test bars should be attached to the castings in such a manner that they will cool at the same rate.

In the case of a large casting, the cooling could be hastened by water applied intermittently, giving time between each application for the internal heat of the casting to reach the outside. This treatment, however, should not be carried to the point of cooling the casting to room temperature or

lower, as it is better to discontinue the water at about 250° F., and allow the casting to air cool to normal temperature.

Heat-treatment of aluminum bronze.—The so-called heat-treatment of aluminum bronze consists in heating the castings to 900° C. (1652° F.), allowing plenty of time for the heat to soak into the casting, then quenching in water which is maintained at normal temperature. The cold castings, which are now hard and possess little ductility, are re-heated in a muffle to 650° C. (1202° F.), and are then allowed to cool gradually with the muffle to room temperature. The result of this treatment is to almost double the yield, and the tensile is not greatly affected, but the elongation is reduced by half. It is rather difficult to apply the treatment on a large scale, especially in the case of large castings. It is better to modify the composition of the alloy so that the effects of heat-treatment can be obtained; or rather an alloy is obtained which will equal heat-treated ordinary aluminum bronze. In this connection it should be known that aluminum bronze does not comprise one alloy, but fully a dozen alloys and perhaps more, the physical properties of which will vary widely, so that almost any strength and ductility within reason can be obtained—in fact, there is no series of non-ferrous alloys that can equal the aluminum bronzes for possibilities in tensile strength and ductility.

The specific gravity of an alloy of 10.50% aluminum and 89.50% copper is 7.43 when cast in sand molds, and 7.45 when chilled by casting in a graphite mold. The Brinell hardness of the sand-cast alloy is 103 using the 500 kg. load for 30 seconds, and of the chilled metal it is 104.

The introduction of iron into the alloy of aluminum and copper favors more rapid solidification, as the rich iron compound first separates and forms a nucleus around which the crystals are built. The effect of the iron is to form many little centers from which the crystal growth can start, which results in crowding the space available, with growing crystals resulting in a much finer-grained alloy than is the case when

iron is not present. The effect of the iron is always to produce stronger and finer-grained metals, hence better alloys.

On figure 31 is shown a Detroit rocking electric furnace, which is used for making aluminum bronze, and properly handled should be efficient for this purpose, as the copper can be melted with a minimum amount of oxidation, as has been determined by chemical analysis of the gases evolved in the furnace when melting copper alloys.

The alloy with a minimum of iron—about 1%—with 10% of aluminum, is largely used for die-casting purposes, and on account of the increase in shrinkage produced by the addition of iron, it is not advisable to go beyond 2% for most die-castings. The physical properties of this latter alloy are considerably better than those of the iron-free metals. The following are typical results: Yield point, 26,000 lb. per sq. in.; ultimate strength, 76,000 lb. per sq. in.; elongation in 2 in., 21%; reduction of area, 19%.

By reducing the aluminum content to 9.5%, the elongation is increased, at the expense of the tensile strength, as shown by the following results: Alloy, aluminum, 9.5%; iron, 1%; and copper, the remainder. In tension the yield point was 21,900 lb. per sq. in.; ultimate strength, 69,800 lb. per sq. in.; elongation in 2 in., 39.5%; and reduction of area, 35.7%. In compression the elastic limit was 16,000 lb.; and compression after application of a load of 100,000 lb. equalled 18.5%.

Addition of zinc.—The above alloy is also subject to the evils of self-annealing, and in order to counteract this trouble it is necessary to increase the iron over 4%, or to introduce zinc, although the addition of the latter results in an impairment of the physical properties of the alloy. The effect of self-annealing on alloys containing 10% aluminum and 1% iron is shown by comparing the following results with the last two given. The test coupons were attached to a casting weighing 100 lb., a block, which was left to cool in the sand mold. The coupon was cut off the casting and was machined to standard size, and gave the following results: Yield point, 25,000 lb.; ultimate strength, 53,100 lb.; elongation, 8% in

2 in., and reduction of area, 11.8%. In compression the elastic limit was 23,000 lb.; and compression after application of load of 100,000 lb., 13.5%.

The effect of additions of zinc is shown as follows: yield point, 29,300 lb.; ultimate strength, 68,540 lb.; elongation, 23.7% in 2 in.; and reduction of area, 21.5%. In compression, elastic limit, 20,000 lb.; and compression after application of load of 100,000 lb. equalled 16%. The composition of this was 85.45% copper, 2.00% iron, 8.25% aluminum, and 4.30% zinc. It was devised by the author, and was found to be free of the harmful self-annealing effects in the case of large castings. The zinc should be added to the copper when molten in the form of 70-30 scrap, and given five minutes to act as a deoxidizer before the other constituents of the mixture are added.

When it is desirable to omit zinc the following alloy can be employed, as it is also free from self-annealing: 88% copper, 7% aluminum, 3% iron, and 2% manganese.

The physical properties of this alloy, as determined by cast-to-size test bars of standard size and shape made in sand molds are: yield point, 25,650 lb.; ultimate strength, 74,000 lb.; elongation, 41.5% in 2 in., and reduction of area, 32.0%. This bronze, as will be noted is better than most alloys of manganese bronze, as the high tensile is combined with very high elongation.

For small castings where high tensile is required, combined with a fair degree of ductility, an alloy consisting of 83% copper, 10% aluminum, and 7% iron is recommended. The physical properties of this alloy, as shown by sand-cast bars are: yield point, 28,300 lb.; ultimate tensile strength, 92,500 lb.; elongation, 19.5% in 2 in.; and reduction of area, 21.2%.

Aluminum bronze is always improved by a second melting, more so than many other alloys. If the test on the above alloy had been made on twice melted metal, the elongation would have been several per cent higher. There is no truth in the oft-repeated statement concerning aluminum bronze that it is brittle when made by the simple mixing of ingredients,

and must, therefore, be cast several times. It is improved by the second melt, but in the majority of cases this re-melting is dispensed with, and the alloy is run directly into castings on the first melt, made from virgin metals.

Casting difficulties.—The difficulties encountered in casting aluminum bronze may be summarized as follows: (1) Piping and shrinking of heavy sections; (2) formation of drossy metal, which is compressed against the walls of the mold by the hydrostatic pressure of the metal; (3) shrinks or “draws” in the inner corners of angles; (4) pear-shaped cavities under the skin of the castings (sand castings); (5) “worm holes” permeating the casting (these holes resemble those made by worms in rotted timber, hence the name); and (6) specks and little pools of white dross under the skin of castings, which are alumina produced by the reduction of cuprous oxide within the copper by the aluminum.

These difficulties are overcome, (1) by careful melting, with the special intention of conserving the deoxidizing powers of the aluminum, using it only as an alloying agent; (2) by using properly dimensioned risers to feed the parts likely to shrink; (3) by the use of chilling influences; (4) by gating with a view of avoiding all agitation of the metal—in which connection it is wise to be informed as to the flow of liquids from pipes, jet effects being especially to be avoided with aluminum bronze; and (5) by using properly compounded alloys which act to eliminate the gases from the bronze.

Effect of copper oxide.—One consideration is that in aluminum bronze between 80 and 90% is copper, and all copper contains more or less oxygen. A certain amount of oxygen is essential to enable the copper refiner to bring his copper to the best condition for sale—the “tough pitch” condition. At this stage the copper is fibrous, and of a fine salmon color when broken, and in this condition the physical properties of the copper are at their best, as is well known. The copper will contain a certain percentage of oxygen, the quantity depending upon the amount of other impurities present, and particularly that of sulphur. Usually, the more oxygen there is

in the copper the less sulphur, and vice versa. The oxygen exists in copper as an oxide, usually cuprous oxide (Cu_2O). If much of the oxide is present, the metal will be low in sulphur because the two react to form a gas, which escapes from the copper when it is permitted to remain liquid in the furnace.

The oxygen gets into the copper partly from the atmosphere; also in refining copper, air is blown into the molten bath, and the oxygen from this source remains partly as oxide. Before the oxygen can form cuprous oxide, it will combine with the impurities in the copper, for which it may happen to possess a greater affinity than for copper, with the result these impurities are oxidized and rise as slags to the surface of the molten copper, leaving the latter in a purified state, and this is the reason the air is blown into the copper. The amount of oxygen in commercial copper of good grade may range from 0.03 to 0.08%, in the form of cuprous oxide, which contains two atoms of copper and one of oxygen. When aluminum is added to the molten copper it changes place with the copper, combining with this oxygen to form alumina, which is a white, non-metallic dross. This is the material that produces leaky castings, and shows as whitish, smeary spots when the bronze is machined. It is distinct from the dross formed in pouring the bronze, and which is caused by dropping or otherwise agitating the metal. This latter material is surface dross on the casting and can be turned off, if stock is allowed on the pattern. If much of this other dross should be formed the result of improper methods of gating the castings, this dross will be folded rather deeply into the skin, and may be beyond removal by machine-tools.

One peculiarity of this dross let loose within the bronze by the deoxidizing effect of aluminum on the copper is that it has a tendency to remain invisible within the metal when the latter has been chilled, and to gather into large masses when the casting is slowly cooled. This is due to the fact that in the case of chilled castings, solidification occurs with such rapidity that the alumina has no time to coalesce, but remains as individual flakes, just where it was produced; while in

the case of a sand-molded casting, it is given time to gather in pools, as other oxides will do.

It will be evident from a study of the above discussion that an oxygen-free copper is desirable for making aluminum bronze castings to be machined or to withstand pressures. In making bronze, the deoxidizing effect of the aluminum should never be relied upon; it is better to deoxidize the copper before adding the aluminum. These various difficulties have militated against the extensive use of aluminum bronze, and

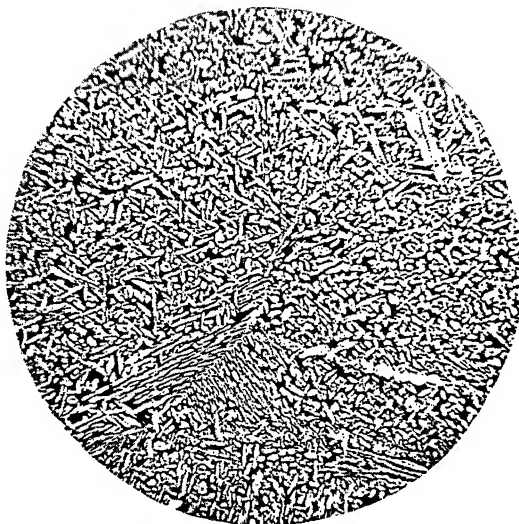


Figure 48.—Aluminum bronze ($\times 20$). Copper, 90%; aluminum, 10%. Chill cast. Etched with ferric chloride and hydrochloric acid.

they are very serious drawbacks to the use of the alloy because they make it costly to shape into commercial forms.

Figure 48 shows a microphotograph of a 90-10 copper-aluminum alloy after it has been cast in a chill mold. The magnification is 20 diameters.*

German aluminum bronze.—One method of making aluminum bronze has been alluded to as the German method. Credit for its introduction into the United States is usually given to Litman, then a laborer in a foundry of a bedstead

* ($\times 20$) = microscopic sign.

maker at Kenosha, Wisconsin, and who in some way got details of the process from Germany, and permission to try it in the molds (chill) in which the cast iron was poured to form the rosettes and jointings required for metal bedsteads. From this humble beginning arose the aluminum bronze die-casting industry of the United States. The following alloy (hardener) is used by one maker of aluminum bronze by this method to carry the iron:

	Per cent
Aluminum.....	67.29
Iron.....	27.04
Vanadium.....	1.98
Sodium.....	3.20
Manganese.....	None
Magnesium.....	"
Calcium.....	"
Silicon.....	0.08

In some cases the sodium was omitted, probably because it became difficult to get ferro-sodium.

Another maker reports the hardener made as follows: In a steel-melting crucible melt 15 lb. of Norway iron, 6 lb. of ferro-vanadium, and 15 lb. of ferro-sodium; add gradually 64 lb. of aluminum, and ingot. The bronze was made in several grades, one formula being as follows: copper, 89%; hardener, 5%; and aluminum, 6%. An analysis of a bronze so made is: copper, 89.41%; aluminum, 9.18%; iron, 1.35%; silicon, 0.07%; vanadium, 0.009%; calcium, 0.02%; and magnesium, a trace. A flux of lime and magnesium chloride would account for the calcium and trace of magnesium.

By varying the amount of hardener the iron was varied, also the aluminum, and one alloy was made of 89% of copper, 5% of hardener, and 6% aluminum.

Some analyses of aluminum bronze made by the above method follow:

Analyses of aluminum bronzes with different hardeners

No.	Copper, %	Aluminum, %	Silicon, %	Iron, %	Manganese, %	Zinc, %
1	82.32	14.50	0.15	3.05		
2	80.50	13.80	.....	5.70		
3	88.16	10.00	.....	.....	1.20	0.64
4	89.40	9.18	0.07	1.35		

This method of making aluminum bronze gives erratic results owing to the difficulty in making the hardener, no two batches being alike on account of variations in the proportion of iron and aluminum, brought about by the difficulty of alloying them in quantity.

By the American method the iron is simply added to the copper as iron, tin-plate clippings being very suitable for the purpose. The following tests show the effect of varying proportions of iron and aluminum on aluminum bronze, the alloys and test specimens being made by the author, and reported by Corse and Comstock * in a paper presented before the American Institute of Metals:

TABLE 21.—*Effect of varying proportions of iron and aluminum on aluminum bronze*

Alloy		Pounds per square inch			Elongation, % in 2 inches	Reduction of area, %	Brinell hardness number
Aluminum, %	Iron, %	Proportional limit	Yield point	Tensile strength			
7	1	14,300	15,700	53,200	56.0	54.2	70
7	2	17,400	18,900	63,000	39.0	35.6	70
7	3	21,300	23,330	74,500	38.0	32.2	80
7	4	22,600	23,600	76,400	38.5	35.7	89
8	1	16,400	19,500	57,100	45.0	43.4	70
8	2	18,200	20,600	63,800	39.0	39.2	80
8	3	24,200	26,000	81,100	36.5	32.9	109
8	4	24,800	26,300	82,100	35.0	32.0	109
9	1	18,500	23,300	69,500	43.0	35.7	77
9	2	22,400	25,800	78,300	30.5	27.4	109
9	3	25,600	28,300	81,700	26.0	26.9	109
9	4	26,400	28,500	83,000	23.0	23.8	109
10	1	19,800	24,000	77,000	24.5	25.2	94
10	2	22,800	26,700	82,600	21.0	19.2	100
10	3	26,100	28,800	86,400	20.0	20.5	109
10	4	27,400	30,000	88,600	17.0	18.5	119

The brittleness imparted to copper by aluminum is nullified to a considerable extent by the addition of the iron; thus an alloy containing 15% of aluminum and no iron would be too brittle to be of service. With 12% of iron and 15% of aluminum the brittleness is overcome, and a very hard alloy

* Transactions American Institute of Metals, vol. x, p. 123.

is the result. Corse and Comstock concluded that there was no advantage in adding more than 4% of iron. Modern alloys, however, frequently contain from 5 to 7% of iron, and it seems probable that an increase in the iron content above 4% is justified in the case of the alloys containing under 10% aluminum.

From table 21 a selection can be made of an alloy having high tensile strength with high elongation, thus an alloy with 7% aluminum and 4% iron would possess these properties. As the iron goes up the shrinkage will increase, therefore, higher and larger feeders are required.

In making molds for the reception of aluminum bronze it is essential that the metal be brought into the mold without any agitation, such as caused by a stream impinging against a core, or two streams meeting, or the metal dropping or issuing from an orifice which acts to give a jet-effect.

Any agitation of the fluid metal results in dross because the film or skin that forms over the surface of the metal is insoluble in the bronze; also it forms instantaneously. Therefore, if this film is rapidly broken, a relatively large amount of dross is formed. Some of this will be non-metallic (alumina), and some of it will be metal, which is entirely coated with an insoluble film, and this detached and insulated metal being crushed against the sides of the mold by the pressure can frequently be picked away from the solidified casting like splinters from wood.

Overcoming casting difficulties.—Difficulties such as piping and shrinking can be traced to a common cause, namely, insufficient feeding. Aluminum bronze requires as much feeding as steel or copper, and considerably more than manganese bronze. It is necessary therefore to use very heavy risers on all thick sections, or else apply chills to ensure that the casting will solidify before the risers, thus making it possible to feed liquid metal to supply the shrinkage cavities in the casting. Piping and shrinking are molding difficulties entirely, and can be prevented by a little study in regard to the places where the risers can be situated to the best advantage.

To produce a maximum of perfect castings of aluminum bronze it is important to realize that it is an alloy possessing peculiarities that distinguish it from ordinary non-ferrous alloys, and that as a consequence it is necessary to handle it entirely different from the ordinary gun-metals and red brasses.

One peculiarity can be illustrated by comparing molten aluminum bronze to soapy water. Aluminum appears to fill the part of a metallic soap when added to other metals; it causes the metal to "lather" in a manner similar to the action of soap in water. This lather is the cause of the drossing of the metal as it fills the molds, producing defects on the surface of the castings. A better understanding of the manner into which molten aluminum bronze should be introduced into a mold is obtained if a few experiments are made with soapy water. Pour the water from one vessel to another, and study the foaming action produced by the soap. It has to be poured without the least agitation. If it was possible to have glass molds into which the soapy water could be poured in various ways, a great amount of useful information could be obtained for application to the problem of gating castings to be made of aluminum bronze, or other alloys containing aluminum.

Aluminum has the same action on all metals. If it is added in small amount to copper, the molten copper will run drossy into molds; and the same is true of yellow brass, monel metal, nickel silvers—in fact all non-ferrous alloys and possibly of ferrous metals also. The soapy water experiments will show that in order to transfer the water from one vessel to another and get no lather it is necessary for it to flow in such a manner there will no agitation of the liquor. If it is allowed to flow gently down the side of the vessel with the latter held at an inclination, there will be no lather, and if we could pour the water so that it entered at the bottom of the receiving vessel there would be no lather either.

Bearing these facts in mind, if aluminum bronze is a "soapy water metal," the only way to get castings free from

dross is to pour them from the bottom. Another important thing is to have the mold in such condition that the bronze will lie very quietly against it. If the metal simmers and fails to lie quiet at any point, there it will foam and produce dross or metallic lather. The sand of the mold must therefore be rammed very evenly, and it must not be too damp; it is best if a little drier than usual, but not necessarily so dry there is difficulty in making the mold.

If the sand is of the proper "temper," and the mold is of the right density, the metal will lie quietly on the sand sur-

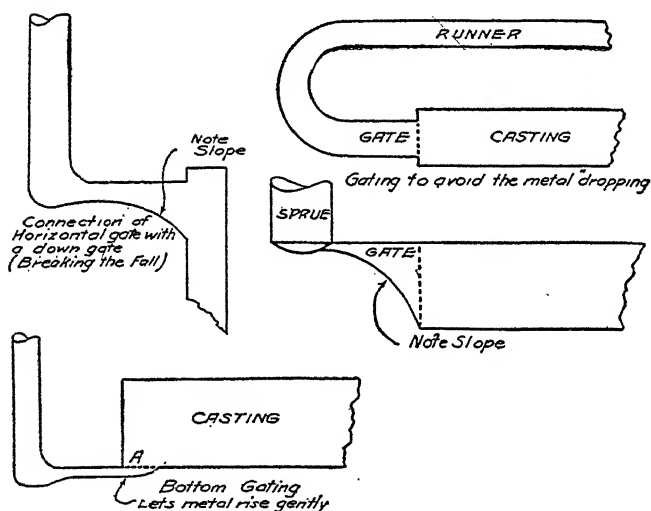


Figure 49.—Different methods of cutting gates for aluminum bronze.

faces after it has been introduced to the mold, and no lather will form on the metal in the mold; and provided none has been formed during the pouring, the casting can not be otherwise than perfect. To get the metal into the mold without lathering is the problem. The best way of gating it is at the bottom, as this will allow the molten metal to rise gently in the mold. While it is important to introduce the metal at the lowest point of the casting, it is equally important to do this in a manner that will avoid the formation of ripples, as each ripple produces a little foam. Thus if the bronze is

introduced to the mold through a "horn gate," dross will be formed at the point of entry and will take the form of a ring, due to the action of the metal spouting up through the horn gate and falling back, produces a fringe of lather which remains as a part of the casting. The horn gate acts like a fountain, because it is generally made tapering in contour, increasing in diameter as it recedes from the casting, the effect being that of a nozzle. To avoid this it is necessary when using horn gates to make the latter of greatest diameter at the point of juncture with the casting.

Experience has shown the best form of gate is a simple flat one. To illustrate: Suppose that a brick is to be molded in aluminum bronze; it should be molded with the thin side of the brick in contact with the cope of the mold, or as the molder would express it, it is molded edgewise. A three-part flask should be used, and all the outline of the brick is molded in the cheek; in the drag and in the cope there is only a flat side. To pour the metal from the bottom, the sprue must be carried through the cope and the cheek to the drag. In order to cut the gate the cheek should not be turned over and the gate cut into the side or end of the brick; that would produce dross. Instead, the cheek is simply lifted away from the drag, and a channel is cut in the latter connecting the sprue to the flat outlines of the brick in the drag, and this channel is continued like a trench for an inch or a little more into the flat side of the brick in the drag, as shown at *A* (see figure 49).

The gate thus forms a lump of metal on the bottom side of the brick when the latter is a casting. A little thought shows that this lets in the metal with the least possible agitation, as the molten bronze flows down the trench into the brick cavity of the mold and then gently rises into the space it must fill. The pattern is of course removed from the mold before attempts are made to cut the gate. A little thought will show that the sides of the trench or gate should be made sloping to allow the metal to slip upwards easily; also that in pouring the metal, it should be done gently to avoid all forcing of the stream which might cause it to spurt, producing

eddies and foam. This foam, which is produced on the liquid metal by a lathering action like that of soapy water, differs greatly from the latter. The lather produced by soap will subside to clear water if allowed to stand, but the foam on the aluminum bronze does not subside, because the metal solidifies before any opportunity is given to subside. The foam or lather therefore is perpetuated in metal. If the bronze is re-melted, the foam disappears, all except a very little dross, which was a film of oxidized metal covering the little bubbles that constituted the foam.

This foam or lather is nothing more than air enclosed by metallic film. It is a mass of bubbles the same as foam

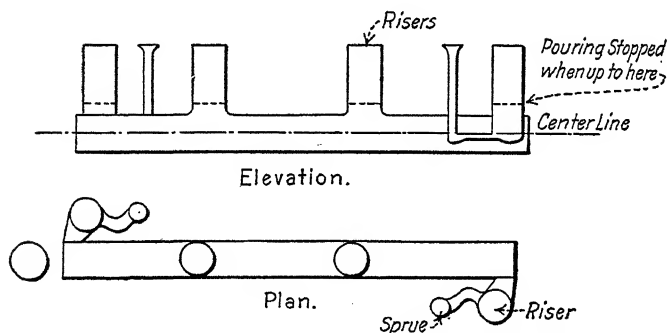


Figure 50.—Illustrating method of pouring aluminum bronze.

on soapy water. With it there may be a little dross entangled, and the mass rises on the surface of the bronze and lodges on the upper surfaces of the casting, where it is compressed by the pressure of the metal behind, producing the well-known drossy spots found all too frequently on castings of aluminum bronze. The same effect is produced in lesser degree in the case of manganese bronze and all metals containing aluminum.

Pouring aluminum bronze.—To overcome the tendency to pipe and shrink, pouring is very important. If the mold is poured like red brass, the risers being filled to the top at one operation, the chances are in favor of piping or the formation of internal shrink-holes. Experience favors a different method of pouring which may be illustrated as follows:

Suppose that we are to pour a rod or shaft, say 6 inches in diameter, the best manner of molding it is the horizontal, with the gates at the sides as shown in figure 50. Two gates should be used, a few inches from either end as shown in the plan. The pouring sprue should be near the riser, the latter being the same diameter as the casting or a little larger, never smaller. The sprue is connected to the riser by a channel shaped like a hook, so the metal will run from the sprue along the curved part of the hook into the riser. There should be a considerable loop in the connection between the riser and the sprue, the idea being to have the liquid stream curve and lose its force before entering the riser; thus the metal enters the latter quietly, and the lathering effect is reduced to a minimum. To ensure solidity of the casting, several risers or feeders are arranged directly on top as shown. The mold surrounding the feeders is built up higher than the top of the cope part of the mold by the use of rings or boxes, but the sprue is not built up any higher than the top of the cope. This makes it impossible to fill the risers completely by pouring down the sprue. The bronze should be poured at both ends of the mold, using a large ladle at one end and a small one at the other. The small ladle or crucible should be hotter than the large one, and it should be reserved until the metal which has been poured from the large ladle has filled the mold up to the dotted line shown in the elevation. At this point the pouring should be stopped for a few seconds; then it should be commenced with the smaller pot from the other end of the mold, pouring very slowly, bringing the metal up into the risers. When the sprue has risen to the limit of its height a bed of sand should be placed thereon, on top of the sand a weight, then the balance of the pouring should be done into the side risers—and very slowly.

The theory of this method is to feed the center of the casting by causing the metal to flow through the same during the time of solidification, thus filling up all cavities that might form during this period. This slow feeding process is so important in making heavy aluminum bronze castings that

the risers should be about twice as high as on ordinary molds, to give plenty of pressure and allow the continual feeding to be kept up almost until the casting has set solid.

Most satisfactory alloys.—For ordinary purposes the best alloy is the following:

A good aluminum bronze

	Per cent
Copper.....	88
Aluminum.....	10
Iron.....	1
30% manganese copper.....	1

Use loosely coiled scrap tin plate or stovepipe iron free from rust to provide the iron, and add it when the copper is melted and hot. After the iron is added, stir the alloy well and add the manganese copper, then follow with the aluminum, a little at a time between stirrings. This will make an excellent alloy, one that will run satisfactorily.

For an exceedingly strong aluminum bronze use the following:

A strong aluminum bronze

	Per cent
Copper.....	84
Aluminum.....	10
Iron.....	4
30% manganese copper.....	2

The strength of this alloy is over 90,000 lb. per sq. in., and its elongation between 20 and 35%. Properly made, it is a very strong and stiff bronze.

For very large, heavy castings of aluminum bronze, the following alloy will give the highest strength, as it does not lose strength when slowly cooled in the same ratio as ordinary 10% aluminum bronze.

Aluminum bronze for large castings

	* Per cent
Copper.....	88
Aluminum.....	7
Iron.....	3
Metallic manganese.....	2

Its physical properties were:

Physical properties of bronze for large castings

	First bar	Second bar
Tensile strength, lb. per sq. in.	73,900	74,500
Yield point, lb. per sq. in.	25,700	26,700
Elongation, % in 2 inches.	41.0	38.0
Reduction of area, %	30.6	31.9

As a general rule the more iron a bronze contains up to 12%, the finer the grain and the easier the metal becomes to cast without difficulties from worm-holes and piping.

MANGANESE IN ALUMINUM BRONZE

The effect of manganese on aluminum bronze appears to be in the direction of toughening the alloy—that is, this element appears to exert some influence on the bronze which has a favorable effect on the elongation of the metal. The addition of manganese to aluminum bronze has been patented twice in the United States, and several times in European countries. The first patent was issued to John A. Jeancore of Newport, Kentucky (U. S. patent 446,351, Feb. 10, 1891), for an aluminum bronze containing approximately 75 to 85% of copper and 2 to 5% manganese. The second patent was granted to P. H. G. Durville (U. S. patent 1,007,548, Oct. 31, 1911), and the composition was 86 to 95% copper, 0.5 to 5% manganese and 6 to 11% aluminum. This second patent is still in force, but it was clearly anticipated by the patent of Jeancore, long since run out.

The idea of these inventors in adding manganese was to improve the casting qualities of aluminum bronze, but that manganese has no effect in this direction has been abundantly proved in practice. Neither is it to be expected that it would, because while manganese has considerable affinity for oxygen, it is so greatly outclassed in this respect by aluminum that it is impossible for it to act in aluminum bronze in any de-oxidizing capacity, and it is this property of manganese that makes it valuable as a strengthener of alloys of copper and zinc. However, manganese appears to have a favorable effect

on the bronze, although it appears to be inferior to iron in this respect.

The following tests will illustrate the influence of manganese on the elongation of aluminum bronze; the first test being on 10% aluminum bronze without any manganese:

Influence of manganese on elongation of aluminum bronze

Tensile strength, lb. per sq. in.....	64,400
Elastic limit, lb. per sq. in.....	22,800
Elongation, % in 2 inches.....	17.0
Reduction of area, %.....	19.6

The second alloy tested contained 89.70% copper, 10% aluminum, and 0.30% manganese:

Influence of manganese on elongation of aluminum bronze

Tensile strength, lb. per sq. in.....	63,800
Elastic limit, lb. per sq. in.....	19,700
Elongation, % in 2 inches.....	49.3
Reduction of area, %.....	42.1

While these two tests are far from conclusive, as it could never be expected that such a difference in elongation would always be found, it is pretty well established that small percentages of manganese are decidedly helpful in aluminum bronze; even when the alloy contains iron as well. It may be remarked that the alloy minus the manganese was fairly good, as much worse results have been obtained from the 10% alloy, although on the other hand better results have been obtained.

In a series of 12 separate tests, the best tensile obtained was 59,700 lb., with 10.5% elongation, and the lowest 37,600 lb., with 2% elongation. A great deal depends upon the skill with which the alloy is made and how the test bars are gated. Figure 51 is a plan of a method of gating aluminum bronze test bars devised by the author, and can be relied upon to produce good results. The test bars are cast-to-size, but the risers are attached to the ends of the grips. Each riser is 2 inches in diameter, the grips $\frac{3}{4}$ inch as usual. In figure 52 the test bar is supposed to be split vertically through each riser and through the body of the test bar. This section shows how the risers should be connected to the grip ends

in order to feed the bar solidly. It will be seen that the shrinkage takes place in the risers because they are so much heavier than the casting itself, and set much quicker than the risers, and the latter consequently are enabled to perform their office of feeding, or supplying liquid metal to make good any voids that might form in the casting, on account of the shrinkage.

An investigation into the alloys of copper, aluminum, and manganese was carried out by W. Rosenhain and C. A. H. Lantsberry at the National Physical Laboratory, Teddington, England, and formed the ninth report to the Alloys Research Committee of the Institution of Mechanical Engineers. This

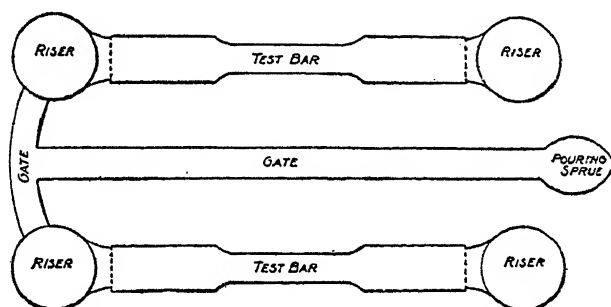


Figure 51.—Good method of gating and feeding aluminum alloys.

report was very complete, and the general inference to be drawn from the investigation is that the effects of adding small quantities of manganese to aluminum bronze is to raise the yield point and tensile strengths without diminishing the ductility; also that manganese increased the resistance of the bronze to corrosion in sea water. The following alloy was well recommended in the report:

Analysis of a British aluminum bronze

	Per cent
Copper.....	87.98
Aluminum.....	8.77
Manganese.....	2.88
Silicon.....	0.06

High manganese, however, seems to increase casting difficulties in commercial working. In one case where the alloy

was made the result was unsatisfactory from a casting standpoint. The metal in the mold at first contracted in a normal manner, a very considerable pipe being formed. In a few minutes, however, after the alloy had to all appearances solidified, an exudation of metal commenced at the bottom of the shrink cavity of the riser, and this bubble gradually rose to the top of the cavity, filling it completely. The casting, as might have been expected, was spongy. The metal was very ductile, being broken with difficulty; but the fractures were spotted with irregular patches of light, yellow-colored metal, also with some darkish colored oxide. The fracture was seamed with small gas vents and showed some

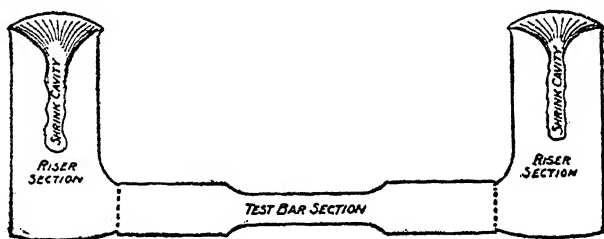


Figure 52.—Longitudinal section through a test bar of aluminum bronze, showing risers.

globular inclusions of gas. On re-melting the alloy, a good casting was obtained. The fracture of the alloy showed much dross. In another attempt, iron was included in the alloy, the composition being as follows:

A poor aluminum bronze

	Per cent
Copper.....	82.50
Aluminum.....	10.00
Iron.....	5.00
Metallic manganese.....	2.50

This alloy also was a failure. After being poured in a sand mold, a large bead of metal oozed as the riser solidified. A gas was evolved with a popping noise during solidification, and ignited with a yellowish flash. Investigation showed that lime had been used as a flux on this alloy, and salt on the

former alloy; but although the lime and the salt had to take the blame for the unsound condition of the metal, nevertheless it also frequently became unsound when neither salt nor lime had been used. The higher the content of manganese in the bronze the greater the need for careful melting in order to get sound castings.

Manganese and iron.—One of these alloys, containing the following:

Analysis of a aluminum bronze tested

	Per cent
Copper.....	81.90
Aluminum.....	11.00
Iron.....	5.00
Manganese.....	2.10

was made and ingoted, and the ingots were re-melted to make the test bars, which showed the following properties:

Properties of above aluminum bronze

Tensile strength, lb. per sq. in.....	101,400
Elastic limit, lb. per sq. in.....	39,400
Elongation, % in 2 inches.....	8.0
Reduction of area, %.....	11.0

Four more tests of the same alloy were then run, and the results were two fairly good appearing bars (cast-to-size) and two poor bars. The results of the two worst bars were averaged, and are shown as under with the two fair bars:

	Average of two	Bar 1	Bar 2
Tensile strength, lb. per sq. in....	91,600	100,900	110,650
Yield point, lb. per sq. in.....	40,050	41,700	37,400
Elongation, % in 2 inches.....	7.8	8.0	10.5
Reduction of area, %.....	8.9	7.9	10.7

It will be seen that like all high tensile alloys they are a little difficult to cast, but if carefully handled the results obtained from bar 2 ought to be regularly duplicated; and it is always possible that the elongation could be brought to a higher point. This would naturally follow the development

of the alloys. The hardness of the metal was 207 Brinell as cast, using the 3000 kg. weight; and when quenched the hardness rose to 270. The object of this discussion is to show that possibilities lie in the alloys of copper, aluminum, and manganese; more especially when iron is incorporated therewith.

MISCELLANEOUS NOTES

Brazing aluminum bronze.—This bronze will braze as well as any other metal, using one-quarter brass solder (50% zinc and 50% copper) and three-quarters borax.

Soldering aluminum bronze.—To solder aluminum bronze with ordinary soft (pewter) solder, cleanse the parts free from dirt and grease. Then place the parts to be soldered in a strong solution of copper sulphate, and place in the bath a rod of soft iron touching the edges to be joined. After a while a copper-like surface will be noticed on the metal. Remove from bath, rinse clean, and brighten the surfaces. These surfaces can then be joined in the ordinary way with common soft solder by using a flux consisting of zinc dissolved in hydrochloric acid.

Mierzinski recommended ordinary hard solder, and stated that Hulot used an alloy of the usual 50–50 lead-tin solder with 12.5, 25, or 50% of zinc amalgam.

Aluminum bronze for jewelry may be soldered by using the following composition:

Hard solder for 10% aluminum bronze.—Gold 88.88%; silver, 4.68%; and copper, 6.44%.

Middling hard solder for 10% aluminum bronze.—Gold, 54.40%; silver, 27.60%; and copper, 18%.

Hercules metal.—An alloy known under this name consists of bronze, 88%; aluminum, 2½%; tin, 7½%; and zinc, 2%.

Aluminum-chromium alloy.—With chromium, aluminum forms a beautiful alloy which can be prepared by a rather tedious operation in the form of crystalline needles, but it has so far found no technical application.

The following alloys have been recommended by G. F. Andrews as being very hard, fine-grained, and possessing great strength:

Number	Aluminum, %	Nickel, %	Copper, %
1	6 $\frac{1}{4}$	21 $\frac{1}{4}$	72 $\frac{1}{2}$
2	10	24	66
3	12	33	55

No. 2 has the color of 10-carat gold and takes a fine polish. No. 3 has a beautiful golden-brown color. No. 1 is similar in color, but of a richer and deeper tone.

Aluminum bronze forges similarly to the best Swedish iron, but at a much lower temperature. It works best at a cherry red, but if this is much exceeded the metal becomes hot-short, and is easily crushed. The temperature for rolling is a bright red heat, and it is a curious fact that if the metal were forged at the temperature at which it is rolled, it would be crushed to pieces. If the temperature in the ordinary muffle in which it is heated is allowed to rise too high, the bronze will frequently fall apart by its own weight. When in the rolls it acts similarly to yellow muntz metal. As it loses its heat much more rapidly than copper or iron, it has to be annealed frequently between passes.

The following examples of rolling were given by the Cowles Electric Smelting & Aluminum Co.: A billet of 10% bronze about 18 by 1 $\frac{1}{4}$ by 1 $\frac{1}{4}$ inches was rolled in a Belgian train to $\frac{1}{4}$ -inch rod, at one annealing. The 5% bronze is harder to roll hot than the 10% metal, but in cold rolling just the reverse is true; a piece of 5% sheeting, 8 inches wide, has been reduced 8 gage numbers when rolled cold at one annealing; while a 10% sheet could not be reduced more than half that number. The billets for rolling can be best prepared by casting in iron molds previously rubbed with a mixture of plumbago, pipeclay, and lard oil. The metal chills very quickly, and smooth castings can be produced, the smooth-

ness depending considerably upon the speed of pouring and the method of gating. With care, the 5 and 10% bronzes can easily be drawn into wire. It is preferable, however, to roll the 5% to $\frac{1}{4}$ -inch rods, and the 10% to a less diameter, and anneal them. The metal thus prepared is much tougher and less liable to break in drawing. The dies must be very hard, or the ordinary wire, and especially the higher grades, are likely to cut them. The speed of the drawblocks must be less than for iron, brass, copper, German silver, or soft steel, and the reduction must be more gradually effected.

CHAPTER IX

COPPER-TIN ALLOYS

Bronze.—The bronzes are the most celebrated of all the alloys. In ancient times, bronze formed an important material for weapons, household utensils, and ornaments; and the opinion was long held by archæologists that among the early civilized people, bronze was used before iron for these purposes, and gave rise to the term “bronze age” being applied to an entire period. This opinion is, however, now considered erroneous.*

The term “bronze” itself is not very old, and seems to have first been introduced in the 15th or 16th century. The Italian author Vannuccio Biringoccio states in his “Pirotechnia,” published in 1550, that alloys of copper and tin were termed “bronzio,” but fails to give the derivation of the word. From the Italian the term passed into the English, French, German, and other languages. Whether the opinion expressed by the French chemist Berthelot, that the alloy was originally called “brondision,” and that its name was derived from the city Brundisium (Brindisi), is correct, must be left undecided.

The term bronze is frequently erroneously applied to mixtures of metals belonging really to the brasses, so there is actually such a confusion of terms that many whose business it is to have an accurate knowledge of alloys do not know what bronze actually is. In the widest sense, bronze may be designated as copper, which, by the absorption of other elements, has become stronger and harder, and capable of being cast. The principal constituent of bronze, therefore, in all cases, is

* Complete refutations of this opinion are found in Dr. L. Beck's *Geschichte des Eisens*, vol. I, pp. 35, 343, 580.

copper, the addition of tin only serving to modify its properties. Tin, though a rather soft metal, possesses, as previously mentioned, the characteristic property of imparting great hardness to copper, so that genuine bronze takes a fine polish, and castings can be worked very clean with the file. On account of these qualities it is especially adapted as a casting material, and its properties can be so changed that it will flow freely, or give a beautiful sound, or acquire a considerable degree of hardness.

The ductility of bronze being but slight, only that containing little tin can be converted into sheet by rolling, the operation being satisfactory at a red heat if the tin content does not exceed 4 to 6%. Bronze, as previously mentioned, being chiefly intended for casting, on account of its hardness finds much application in the machine industry for articles which cannot be made of iron or steel.

IMPURITIES IN BRONZE

Bronzes consisting of pure copper and tin show definite properties according to the proportions of those metals. However, in making a chemical analysis of commercial bronze, it will almost invariably be found to contain a small quantity of other metals, but a sharp distinction should be made as to whether these admixtures are accidental or intentional. Besides iron, manganese, nickel, lead, and zinc, very small quantities of phosphorus, arsenic, sulphur, or antimony, are sometimes found; and as a small quantity of any of them suffices to change considerably the properties of the alloy, it is important to pay some attention to their influence. Before starting a discussion on these properties, it may be remarked that the difficulties many manufacturers find in obtaining alloys of determined qualities is due to the fact that they do not use as pure metals as possible, but melt down with them certain quantities of old bronze, which, as a rule, contains zinc, iron, or other foreign metals.

Zinc and lead.—Zinc acts on the properties of bronze in various ways. Added in very small quantity it has a bene-

ficial influence, the molds being filled out sharper and the castings obtained freer from blow-holes. If the addition of zinc be exceeded above a certain limit, the alloy loses the characteristic properties of bronze, especially the warm color, which passes into a more or less dull brass yellow. Besides, bronze containing too much zinc does not acquire on exposure to the air the beautiful green coloration termed "genuine patina," but one shading into black. The peculiar patina of a velvety-black color found upon old Chinese bronzes is said to be the result of an addition of lead, and it is a fact that all Chinese bronzes contain a certain quantity of lead.

The influence of lead on gun-metals (copper-tin alloys) has been studied by R. T. Rolfe of Bedford, England, who found that up to about 1.5% lead slightly increased the strength and considerably increased the ductility of such alloys, and it was only when this amount was exceeded that any decrease in strength or ductility occurred. It was possible that from 2 to 3% of lead could be added to gun-metals, without bringing the physical properties below the Admiralty requirements. Therefore, Rolfe concluded that the prejudicial results of lead had been exaggerated. Primrose, on the other hand, found that the progressive addition of lead to gun-metals led to a steady decrease in strength and ductility, while Dewrance found a great advantage of gun-metal containing 0.5% lead over lead-free gun-metal. The experience of the author of this volume has been to the effect that the substitution of 0.5% of lead for the same amount of tin, in the 88-10-2 copper-tin-zinc alloy resulted in a marked improvement, and tests of this alloy will be given later on.

Aluminum.—In regard to other impurities, Rolfe found that in the case of aluminum, it oxidized and caused oxide films between the grains of the metal. It increased the amount of liquid contraction, and, according to Johnson, was also responsible for a greater resistance on the part of the alloy to absorption of the Delta constituent upon annealing. It has been the experience of many founders that a very little aluminum, insufficient to show on the skin of the castings,

caused marked changes in the behavior of the alloy, during foundry operations. When the castings are broken off the gates while hot, the normal metal will break at that temperature with a straight fracture, tearing in, neither to one side or the other; but the aluminized metal will have a fibrous tear, and the fibers will frequently reach into the casting, not like a break along the boundaries of crystals, but with long slivers of fibers, which are usually colored a deep gold on the torn boundaries. For sand-castings, aluminum is very troublesome in the case of gun-metals; but for die-castings, it has to be used with these alloys.

Antimony.—This metal, according to Rolfe, added in increments of 0.5% up to 1.5% hardened the alloy, and caused a progressive falling off in the strength and ductility. It also caused unsoundness in both chill and sand castings. It has no noticeable effect on the microstructure of chill castings. Arsenic on the other hand does affect the microstructure, its most interesting effect being in the direction of increasing the proportions of secondary Alpha, and of eutectoid. Bismuth produces brittle intercrystalline films, and is thus very objectionable even in the smallest quantities.

Iron.—This metal gives rise to hard spots, which Dewrance and Primrose claim to be a tin-iron compound. (It is more probably a tin-iron-carbon combination; see remarks on Manganese Bronze.) Iron, in the absence of carbon, will alloy with copper alloys, as is proved by the fact that added as a flux of yellow prussiate of potash, it alloys perfectly with and greatly improves the tone of bell metal, and is therefore used for this purpose.

Gulick states he found that iron increased the strength, but decreased the ductility of gun-metals, while Johnson claims that it increases strength without any loss of ductility. The statement of the former appears to be more in accordance with the facts, as gun-metals and composition deoxidized with iron, will have higher tensile and lower ductility, according to the experience of most foundrymen.

Manganese.—Used as a deoxidizer, manganese markedly improves both the tensile strength and elongation of such as the 90-10 copper-tin alloys, and in the case of this particular alloy manganese is superior to phosphorus. Phosphorus and manganese work well together, the former being used in very small proportion when the new metals are alloyed, and the latter when the ingoted first melt, is re-melted.

Nickel.—It has been stated that nickel gives rise to unsoundness, but this effect is not observable when it is added as a rich alloy of copper, nickel, and tin, deoxidized with phosphorus, which is the best way to use it in bronze. When so used, a considerable reduction of the tin content can be made, and an alloy of the same physical properties will result. This method of saving tin was practiced to a considerable extent during the War.

Silicon.—It has been proposed to use silicon as a deoxidizer of gun-metals, but this element is very uncertain to handle as it has to be kept so low, and it is difficult to get the correct weights in ordinary foundry operations; and should any lead get into the alloy the result will be the formation of enough dross to ruin the castings.

PROPERTIES OF BRONZE

Color.—The physical properties of bronze are also materially affected by other conditions than the chemical composition, chief among which is the rapid or slow cooling off of the fused material, which exerts so powerful an influence that the product with an equal chemical composition may acquire an entirely different appearance. According to the tin content the color of bronze varies between red and white, and with a considerable amount of tin it passes into steel-gray. Generally speaking, tin exerts a greater influence on the color than zinc, the alloy with a comparatively small tin content exhibiting no longer a red, but a white color.

Alloys containing 90 to 99% of copper retain a pure red color; with 88% of copper it rapidly changes to orange-yellow,

and with 85% becomes pure yellow. With a decrease of the copper content to 50% the respective alloys show a slightly yellowish-white color. It is a remarkable fact that alloys with a content of between 50 and 35% of copper are distinguished by a pure white color, while those containing up to 65% of tin show a steel-gray color. With a still greater percentage of tin the color of the alloys again becomes pure white. As bronzes of various compositions are extensively used in the construction of machinery and ordnance, many physicists have occupied themselves with the determination of the proportions of ductility and hardness of the various alloys; but it cannot yet be said with certainty when a bronze is hardest, toughest, most ductile, etc., and we have only approximate numbers for these proportions, which may briefly be summed up as follows:

Ductility.—Alloys with 1 to 2% of tin show nearly the same ductility as pure copper. They can be worked in the cold under the hammer, but crack more readily than pure copper, this cracking showing itself especially in attempting to stretch a plate of the alloy under the hammer. The ductility decreases rapidly with an increase in the tin content; an alloy containing 5% of tin can only be worked with the hammer at a red heat, but soon cracks when it is attempted to hammer it in the cold. Alloys containing up to 15% of tin can no longer be hammered even in a warm state. The figures given show that tin reduces the ductility of the copper. Its solidity is, however, considerably increased. Alloys with about 9% of tin show, according to most statements, the greatest strength of all bronzes, and in accordance with this, gun-metal generally contains tin approaching that limit. According to other statements, alloys with about 15% possess the greatest hardness and strength. The maximum for hardness and brittleness lies between 28 and 35% of tin.

From the results of more recent investigations regarding the strength and hardness of bronzes, the following may be deduced: The hardness increases constantly until the composition of the alloy has reached 72.8 parts of copper and

27.2 of tin. With an increase in the tin the hardness decreases, it being, in a mixture of 33.33 parts of copper and 66.66 parts of tin, nearly exactly the same as that of pure copper. Above this proportion the hardness decreases considerably, and with a compound of 90 parts of tin and 10 parts of copper it is but little more than that of tin.

Effect of forging.—Alloys rich in copper undergo a peculiar molecular change when forged. By subjecting alloys containing somewhat less than 94% of copper to continued forging they become as hard as steel, but unfortunately acquire at the same time such a degree of brittleness that they can only be used for purposes where they are not exposed to heavy shocks.

Though the hardening of bronzes by forging is remarkable, there is another phenomenon yielding still more extraordinary results. By quickly cooling off red-hot bronze in cold water it almost loses its brittleness, and can then be used for many purposes, an alloy containing 84 parts of copper and 16 of tin being most suitable for the purpose. Even a fairly thick article acquires a certain flexibility through its entire thickness, which it retains after forging. If it is desired to restore an article to its original hardness after tempering, it need only be brought to a red heat and slowly cooled. According to the above the behavior of bronze in this respect is just the reverse of that of steel as the latter by quick cooling, becomes very hard and brittle, and by slow cooling soft and malleable. The density and hardness of bronze decrease with quick cooling and increase with slow cooling, hence, bronze articles quickly cooled have a deeper sound, a fact well to be considered by bell-founders.

Strength.—The density and hardness, as well as the power of resistance against cracking, depend on the composition of the alloy as much as on the manner of cooling the cast articles. According to practical experience, the greatest strength is secured by endeavoring to obtain the crystals of the alloy as small as possible, even the material of the mold in which the casting is made exerting a great influence on the grain, and

through this on the strength. Articles must be cast at a higher temperature in iron than in sand molds, 1600° C. (2912° F.) being required with the use of the former, and 1400° C. (2552° F.) suffices with the use of sand molds, especially for larger castings.

Composition and density.—Alloys suddenly subjected to a high pressure, such as gun-metal, must have an especially high degree of density, this being, however, not directly proportional to the composition, as will be seen from table 22 following:

TABLE 22.—*Composition and density of copper-tin alloys*

Composition		Density
Copper	Tin	
96.2	3.8	8.74
94.4	5.6	8.71
92.6	7.4	8.68
91.0	9.0	8.66
89.3	10.7	8.63
87.7	12.3	8.61
86.2	13.8	8.60
75.0	25.0	8.43
50.0	50.0	8.05

Bronze being used exclusively for casting, it is necessary to discuss briefly the temperatures at which the various alloys become fluid. According to Künzel, to whose researches we are indebted for much information regarding the properties of bronze, the various alloys show the following melting points:

TABLE 23.—*Composition and melting points of certain copper-tin alloys*

Composition		Melting point, ° F.	Melting point, ° C.
Copper	Tin		
95	5	2480	1360
92	8	2354	1290
90	10	2282	1250
89	11	2228	1220
86	14	2102	1150
84	16	2012	1100
80	20	1868	1020

Contraction.—Articles cast of bronze contract on solidifying, as is the case with other mixtures of metals, the degree of contraction depending upon the temperature of the alloy and its composition, and amounts to $\frac{1}{130}$ to $\frac{1}{77}$ of the bulk of the various mixtures.

The difficulty of obtaining perfect castings is, however, increased more by the chemical behavior of the alloys towards the oxygen of the atmosphere than by contraction. In subjecting the bronze to fusion, the tin shows greater affinity for oxygen than the copper, hence, by re-melting the bronze several times it becomes sensibly richer in copper by a portion of the tin being lost by oxidation. To prevent a change in the qualities of the alloy, a larger quantity of tin is generally added than the finished product is to contain, so that the tin lost by volatilization is equal to the excess added, and the alloy obtained shows exactly the desired composition.

Another effect of the oxygen consists in the oxides of the constituent metals of the bronze—stannic oxide and cuprous oxide—dissolving in the alloy, whereby its strength and toughness are considerably decreased. In the manufacture of ordnance, part of the metal required is generally obtained by melting down old cannon, the mixture of metals thus obtained frequently contains large quantities of the metallic oxides in solution, and the toughness and strength of the new alloys are considerably impaired.

The melted bronze shows another property frequently observed in other metals, especially in silver, namely, it can absorb a considerable quantity of oxygen, but allows it to escape in a gaseous state on cooling. If now, as is done in most cases, the castings are rapidly cooled off, the bronze becomes so thickly-fluid that the absorbed oxygen cannot escape, and the resultant castings are full of innumerable, though microscopically small, hollow spaces, which injure the density and strength of the alloy.

The absorption of oxygen, as will be seen from the above, being very injurious to the qualities of the bronze, precautions must be taken to protect the metal from the effect of

oxygen, in fusing as well as in casting. The best preventive against the absorption of oxygen is to protect the alloy by a layer of glowing charcoal, and to effect a reduction of any oxides formed by vigorous stirring of the fused alloy. Though oxidation is counteracted by these means, it is not possible by them to remove the oxygen reaching the alloy from such sources. Phosphorus has, however, been found to be an excellent agent for the deoxidation of the oxides dissolved in the metal, but it has to be added very carefully, since a small quantity in excess exerts great influence on the properties of the alloy itself. In most cases an addition of $\frac{8}{1000}$ to $\frac{10}{1000}$ (0.008 to 0.010) suffices for the reduction of the oxides in solution.

Loss in melting.—As tin oxidizes more readily, it is generally advisable to fuse the copper first, and then quickly introduce the tin. The heat should at the same time be increased to keep the alloy very thinly-fluid, the union of the two metals being accelerated by these means; at the same time the melted mass should be stirred vigorously. Even by taking all these precautions, the loss in melting and casting always amounts to 1 to 10% of the weight of the metals used. Where the loss is only 1 or 2%, the work may be considered excellent.

The loss of metal, as well as the qualities of the castings, are also considerably affected by the construction of the melting furnace. The more quickly the furnace can be heated to the temperature required for reducing the alloy to a fluid state the better it is for the purpose, as even with perfect protection against the action of oxygen, changes injurious to the homogeneity of the castings take place with long-continued fusion. If a bronze be intentionally kept molten for a long time, a white alloy, rich in tin, is formed in it and is clearly perceptible in the castings. The alloy is no longer homogeneous, but actually consists of a mixture of several alloys differing considerably in density, power of resistance and strength, which seriously impairs the properties of the entire mixture. This separation or liquation of the alloy into

Copper-tin Alloys

two or more compounds occurs specially in mixtures most frequently used—that is, such as contain between 5 and 20% of tin. From alloys containing a lower or higher percentage of tin, homogeneous castings are more readily obtained.

Liquation.—Most bronzes have a strong tendency towards liquation, and it is difficult to make thick castings from them without this change becoming perceptible. It is particularly plain to the eye with an alloy containing about 10% of tin, the reddish fracture of which, if cooling has not been effected very rapidly, shows white spots—so-called tin stains—the result of an alloy richer in tin.

Since the liquation of an alloy rich in tin is promoted by slow cooling, the melted mass, which has a temperature of about 2552° F., must be cooled down as quickly as possible to 932°, at which point the alloy richest in tin solidifies. This is, however, connected with many difficulties, especially in casting large pieces, such as cannon and bells, for which a perfect homogeneous metal is absolutely necessary.

The behavior of the solidified alloys towards the atmosphere varies according to their chemical composition—that is, they oxidize, on exposure to the air, in a shorter or longer time, acquiring thereby a color ranging from a beautiful green to black. This layer of oxide, which contributes much to the æsthetic effect produced by an article of bronze, is an important factor, especially to those occupied with casting statues, and the like, and will be referred to later on.

Melting and casting bronze.—The quantity of bronze to be prepared at one time varies considerably, and may amount to a few ounces, or hundreds or thousands of pounds. Though the mode of preparing the bronze is the same in all cases, certain difficulties arise in casting small articles as well as large ones. For casting small pieces, a finished alloy of the desired proportion of metals is generally used, it being difficult to hit the exact composition required in preparing small quantities of bronze. The fusion, in this case, is always effected in crucibles, especial care being required to prevent

oxidation of the tin as much as possible. The crucibles are placed in a wind furnace, and the surface of the bronze is kept carefully covered with pulverized coal, anthracite being best on account of its great density.

The preparation of large quantities of bronze, such as for casting bells, cannon, or statues, is effected in reverberatory furnaces capable of holding up to 10,000 lb. or more.

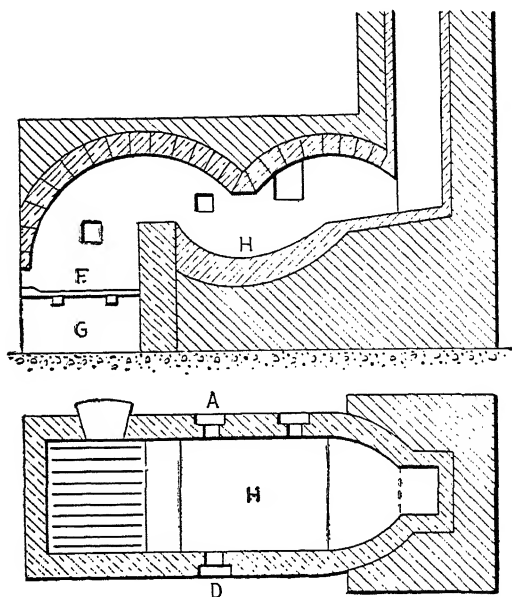


Figure 53.—Small reverberatory used for melting bronze.

The copper is first melted, and when fluid, the scrap bronze is added. When all is converted into a uniform mass, the tin, previously heated as much as possible, is introduced in small portions. Immediately before the introduction of the tin, the fire must be increased in order to compensate for the consequent reduction of the temperature, and to keep the metal in a thinly-fluid state. Figures 53 and 54 show the arrangement of a reverberatory furnace especially adapted for melting a medium quantity of bronze. *F* is the firebox,

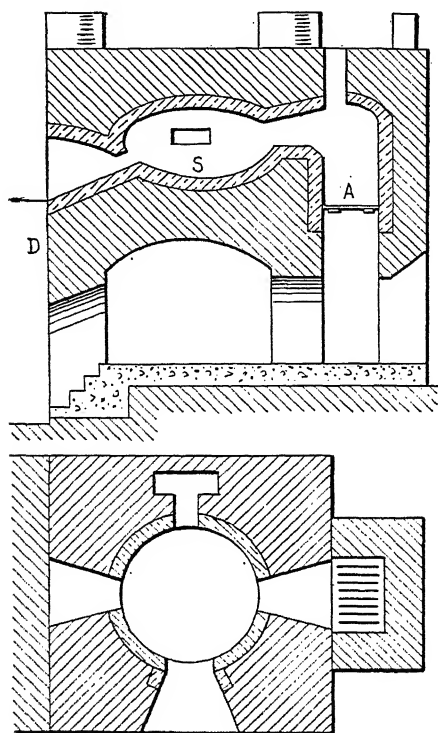
and *G* the ash-pit. The metals to be melted are placed on the trough-shaped hearth *H* (figure 53), while the aperture *D* serves for the introduction of the charge and for taking samples. The finished bronze is run off through *D*. For large articles, loam molds are used almost exclusively, sand molds being but seldom employed. While, as previously stated, it is advisable in casting small articles not to have the bronze too hot, for large objects it should be very hot in order to render the production of uniform castings possible by keeping the mass in a fluid state for some time, and thus giving the gases evolved, as well as the oxides, a chance to rise to the surface.

The base of the hearth in this furnace is, as will be seen from the illustration, trapeziform, though there are designs in which it is elliptical or oval, or even circular, the latter form being frequently used, for instance, in casting statuary bronze. Figure 54 shows the construction of such a furnace, *S* being the hearth, *A* the firebox, and *D* the foundry-pit in which the mold is placed. The aperture above *S* serves for the introduction of the metals, and that above *D*, which is closed during the melting period with a plug of clay, for running off the fused metal.

In a furnace of this kind, up to 26,500 lb. of bronze can be melted for one casting. It is possible to construct furnaces of larger dimensions, but, on account of more uniform heating, it is best to use in this case several fireplaces arranged on the periphery of the melting hearth.

An interesting though unusual type of melting furnace for bronze is the Herbetz steam-injector furnace sometimes seen in French foundries and illustrated in figure 55; but the furnace operates without steam, only the natural draught of an iron chimney 82 feet high being used. The furnace shaft *A*, 12½ feet high and 2¾ to 3 feet in diameter, contains the furnace. It is supported in a frame by four cast-iron columns *B*, to which is also secured the movable hearth *C*, so that it can be raised or lowered at will by means of screws *a*, and the operator can regulate, according to the quality of

the coke used, the width of the slit *b* between the edges of the shaft and the hearth which serves for the admission of air. At *c, c* are peep-holes; *d*, a Langen apparatus for closing the mouth of the shaft; and *e*, a pipe conducting the gas into the chimney *D*. This furnace has the following advantages over a crucible furnace: (1) No crucible and blast, (2)



laboratory furnace.
hearth.

production of a beautiful fine-grained bronze on account of the evaporation of zinc present as contamination, (3) consumption of only about 12% of coke against 40% by crucible furnaces, (4) more rapid fusion, and (5) production of castings of any desired size with but one tapping.

It will, of course, be understood that the composition of bronze must vary considerably according to the purpose for

which it is to be used. In practice, a large number of alloys are distinguished, according to their application by various names.

Before proceeding with the description of the preparation of the alloys for such purposes, it will be convenient to refer briefly to the bronzes of prehistoric times. It is well

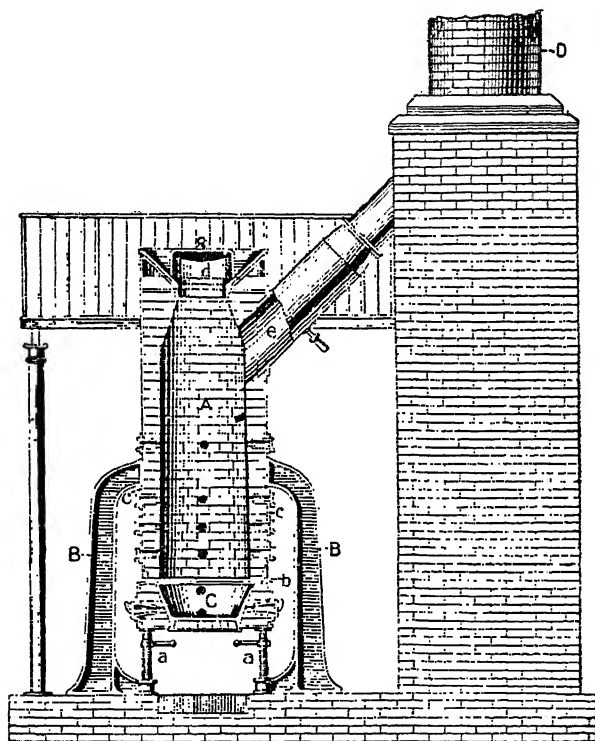


Figure 55.—Herbetz steam-injector furnace.

known that bronze was extensively used by the ancients for coins, weapons, tools, and ornaments. It might be supposed, at first sight, from the castings of the ancients, that they possessed some expeditious and simple means of making their enormous and numerous productions; but on closer inspection this conclusion appears untenable, as many analyses of their alloys have demonstrated the fact that their bronzes

were not a constant composition of copper and tin, but frequently contained foreign metals, which cannot be considered as intentional additions, but only as accidental contaminations. Hence, the success of a bronze of good composition was, no doubt, at that time, more a matter of accident than is possible with our present knowledge of alloys; and the analyses of old bronzes can only give us suggestions concerning the behavior of the metals in the presence of substances considered as contaminations, without, however, contributing to the advancement of information in regard to the alloys. Modern investigations, especially regarding gun-metal, are so exhaustive concerning the influence of the chemical composition of the alloy on its physical qualities as to enable us to prepare alloys with any desired properties.

While the older bronzes, especially those of Greek origin, consisted almost only of copper and tin, in the older Roman coins considerable quantities of lead are frequently found, which must be considered as an intentional addition. Zinc seems first to have been intentionally added to bronze in the beginning of the present era. The exact composition of bronze has only been determined by chemical analysis, the effect produced by the different elements upon the properties of the bronze, as well as the influence upon its physical qualities by rapid or slow cooling off, being now well understood. Below is given the composition of some ancient bronzes:

TABLE 24.—*Composition of some ancient bronzes (per cent)*

	<i>a</i>	<i>b</i>	<i>c</i>	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>
Copper.....	86.38	80.91	88.70	92.07	68.42	81.76	83.65	88.06	95.0
Tin.....	1.94	7.55	2.58	1.04	0.94	10.90	15.99	11.76	4.5
Zinc.....	3.36	3.08	3.71	2.65					
Lead.....	5.68	5.33	3.54		22.76	5.25			0.2
Antimony.....	1.61	0.44	0.10		0.67				
Iron.....	0.67	1.34	1.07	3.64	4.69	0.15	trace	trace	0.3
Nickel.....					0.78	trace	0.63	trace	
Cobalt.....						1.22			
Sulphur.....		0.31							
Arsenic.....					1.48				
Phosphorus.....							0.05	0.03	
Silica.....	0.10	0.16	0.09	0.04					
Loss.....	0.26	0.79	0.21	0.56	0.26	0.72		0.15	

a to *d* are from Japanese temples, according to Mauené; *e* is an Egyptian figure, according to Flight; *f* is from Cyprus of the time of Alexander the Great, according to Reyer; *g* is an axe from Limburg with a thick coat of green patina, according to Reyer; *h* is a chisel of a dark yellow color from Peschiera, according to Reyer; and *i* is an old German chisel, according to Boussingault.

A Japanese bronze statue of Buddha weighing 450 tons is composed of 98.06% copper, 1.68% tin, 0.21% mercury, and 0.05% gold.

Ordnance or gun-metal.—Bronze is said to have been used by the Arabs for casting cannon as early the beginning of the 12th century; while in Germany the first bronze cannon were manufactured towards the end of the 14th century. Prior to that, after the invention of gunpowder, cannon of wrought-iron bars put together in the shape of a barrel and hooped with iron were used. While wrought-iron guns soon burst as a result of the crystalline texture formed, cast-iron cannon of mottled iron are much more durable; but modern cannon of steel are lighter, cheaper, and more durable than bronze.

Probably more money and labor have been spent by various countries on the study of gun-metal than on any other alloy in order to find out the best alloys for the manufacture of ordnance.

The properties demanded from a good gun-metal follow from the use of the cannon themselves. In firing a cannon, an enormous pressure, amounting to over 2000 atmospheres, is suddenly developed. To resist this pressure, the material must possess great toughness, and cannon manufactured from bronze lacking this toughness generally burst with the trial shots, for which especially large charges of powder are used. Gun-metal must further possess a high degree of hardness, as in firing, the projectile strikes one or more times against the walls of the cannon, it being impossible to give the same size mathematically accurate to the caliber of the piece and that of the projectile. If the bronze be not sufficiently hard, the interior of the cannon loses its cylindrical form after a

few shots, which is detrimental to the accuracy of the shot. Finally, it must be considered that the gases evolved by the combustion of the powder attack the metal of the cannon, hence, the composition of the bronze must be such that this chemical action is reduced to a minimum.

Briefly stated, good gun-metal must be very tough, capable of resistance, hard, and indifferent towards chemical influences, conditions which vary much from one another and are difficult to combine.

In order to obtain these properties, all possible additions have been made to the actual bronze (consisting of tin and copper), and analyses of ordnance metal of different periods and various countries plainly show the efforts made to arrive at a correct composition of gun-metal by certain admixtures. In modern times the addition of foreign metals—with the exception of a small quantity of zinc, or, in special cases, of phosphorus—seems to have been abandoned, the quality of the bronze being adapted to the desired purposes by suitable treatment in melting and casting. In older pieces a series of foreign metals is found, some of which, nickel and cobalt, for instance, must be considered as accidental contaminations, since the preparation of these metals in a metallic form has only been known during more recent times. Iron, if present in considerable quantity, is no doubt an intentional addition; and the inclusion of bismuth can be explained by the fact that in connection with arsenic it was formerly used as a flux in the bronze mixture.

The tin content of bronze which has been found most suitable for casting ordnance varies between 9 and 11 parts to 89 to 91 parts of copper. This composition corresponds closely with that used for weapons by the Greeks and other nations in ancient times.

So many details essential for the success of the operation are connected with the melting and casting of alloys for the manufacture of ordnance, that a special volume would be required for a complete description; so we can only give the

merest outline, and must refer those especially interested to the treatises published on this subject. The principal requisite of an alloy answering all the demands of a good ordnance bronze is the production of an entirely homogeneous casting, which it is endeavored to attain by solidifying the alloy under conditions allowing a uniform cooling off. The molds are always placed in a vertical position, and as the upper portions of the casting frequently show a different composition from the lower, this drawback is counteracted by using an excess of bronze, so that the finished casting has a long piece on top, the so-called "dead-head" or "sullage-piece," which is later on sawed off and re-melted with a new charge. This dead-head contains the greater portion of the alloys of dissimilar composition, and also the so-called "waste," consisting of oxidized metal.

In casting ordnance, old cannon are frequently melted in, this practice producing a favorable influence upon the homogeneity of the resultant new material. The loss of tin by oxidation is also smaller, as tin once united with copper does not oxidize as readily as in the preparation of new alloys. Great experience is required to obtain a homogeneous product, and after the metals are melted, samples must be taken and examined, so that if the composition be not correct it can be improved by a suitable addition of copper, tin, or old bronze, as may be found desirable. As a considerable time is required for the newly added metals to form a homogeneous combination with the material already melted, great precaution is necessary to prevent oxidation of the metals as much as possible. Strictly, it would be best to use gas only for melting bronze mixtures, as with this mode of firing not only can the heat be regulated at will, but a flame containing no free oxygen, and consequently capable of completely preventing the formation of waste, can be passed over the fusing metals.

The temperature at which ordnance bronze is cast also exerts considerable influence upon its physical properties, about 2200° F. being the most suitable. Cannon cast at this

temperature are distinguished by great uniformity, throughout the entire mass, and there need be no fear of the separation of the so-called tin-spots, one of which, if in a place especially subjected to strong pressure in firing, will quickly render the entire piece useless.

Ordnance bronze should be cooled off rapidly, this also decreasing the danger of the formation of tin-spots. Iron molds are frequently used, but they must not be too cold, otherwise the layers of bronze coming into immediate contact with the iron solidify so quickly as to prevent the mobility of the still fluid mass in the interior; which would produce an unequal tension of the molecules, in consequence of which the piece might burst with the first shot. In many ordnance foundries sand molds are used, there being a great diversity of opinion as to which method of casting is the most suitable. Cannon are generally cast solid, and the cylindrical cavity is formed by boring out this solid mass. Some founders, however, consider it preferable to cast the piece over an iron mandrel, which is sometimes so arranged that water can circulate in it in order that the parts nearest to it may quickly solidify and become as hard as possible.

The ordnance bronze known under the name of "steel bronze" is prepared in the Austrian arsenals, the method of melting and subsequent treatment in casting being kept secret. It is only known that the bronze contains 8% of tin, and that the casting is effected in cold iron molds. The peculiarity of the process of manufacturing, ordnance from steel bronze (also called "Uchatius bronze," after its inventor) consists in the piece, after being finished, being subjected to a peculiar mechanical treatment, as follows: The caliber of the piece is made smaller than it is finally to be, and is then gradually enlarged to the required diameter by steel cylinders with conical points being forced through the cavity with the assistance of hydraulic pressure. As a result of this peculiar treatment the cavity is, so to say, rolled or forged, the bronze acquiring the greatest power of resistance in those places which in firing are subjected to the greatest pressure.

The following table (25) shows the composition of ordnance bronze of various times and different countries:

TABLE 25.—Composition of ancient and modern ordnance bronze

	Copper	Tin	Lead	Zinc	Iron	Brass
United States.....	90	10				
France (1780).....	100					61.0
France (modern).....	90.09	9.9				
Prussia.....	90.90	9.1				
England.....	89.30	10.7				
Savoy (Turin, 1771)...	100	12.0				6.0
Russia (1819).....	88.61	10.7			0.69	
Lucerne (Switzerland)...	88.929	10.375	0.062	0.419	0.110	
Cochin China.....	77.18	3.42	13.22	5.02	1.16	
	93.19	5.43			1.38	
China.....	71.16			27.36	1.40	
	89.58	10.15				
Turkey (1464).....	95.20	4.71				

Tests of ordnance bronze.—Three old 12-pounder guns cast in 1864 were tested at the Watertown Arsenal (U. S.) with interesting results, a chemical analysis being shown below:

Chemical analysis of gun-metal

Gun No.	Part	Copper, %	Tin, %	Zinc, %	Iron, %
1	Breech	88.63	9.57	1.80	Trace
1	Muzzle	88.85	9.40	1.74	"
2	Breech	90.65	9.35	Trace	"
2	Muzzle	90.50	9.50	"	
3	Breech	90.90	7.60	1.50	
3	Muzzle	90.97	7.75	1.48	

The guns were cut into sections in the lathe, and longitudinal segments were taken out by the planer, and from the latter tensile specimens were turned, from which the properties of the metal were ascertained. Both chemical and physical tests were taken from breech and muzzle of each gun, and it will be noted from the analyses there there was no particular segregation to any one part of the gun. Presumably the breech was cast down, but the tin favors neither breech nor

muzzle. The formula of the bronze as charged, the case of each gun was as follows:

Composition as charged

Gun No.	Copper, %	Tin, %	Zinc, %
1	88.00	10.00	2.00
2	90.00	10.00	
3	90.00	8.00	2.00

The physical properties of No. 1 gun were as follows:

	Breech	Muzzle
Tensile strength, lb. per sq. in.....	39,000	41,440
Elastic limit, lb. per sq. in.....	14,000	14,000
Elongation, % in 2 inches.....	22.5	33.7
Reduction of area, %.....	19.5	29.1
Specific gravity.....	8.818	8.724

The color of the fractured surfaces at the breech was a uniform, dull, lavender yellow; and at the muzzle a uniform golden yellow.

Tests on No. 2 gun gave the following:

	Breech	Muzzle
Tensile strength, lb. per sq. in.....	43,800	47,000
Elastic limit, lb. per sq. in.....	14,000	14,000
Elongation, % in 2 inches.....	31.1	40.7
Reduction of area, %.....	32.1	32.4
Specific gravity.....	8.595	8.731

The color of the fracture at the breech was a uniform lavender yellow, and at the muzzle a uniform dark yellow. The metal was considerably better than that in No. 1 gun.

Tests on No. 3 gun gave the following:

	Breech	Muzzle
Tensile strength, lb. per sq. in.....	43,070	35,130
Elastic limit, lb. per sq. in.....	13,000	12,000
Elongation, % in 2 inches.....	42.8	21.3
Reduction of area, %.....	33.5	29.1
Specific gravity.....	8.856	8.779

The color of the fracture at the breech was a uniform, reddish-yellow; and at the muzzle a reddish-yellow with spongy spots.

The following experiments were then undertaken: Samples of metal were cut from No. 2 gun, and were melted with 2% of tin, thus raising this metal to around 11.50%. This re-melted metal was found to have the following properties:

Properties of gun-metal with extra tin

Tensile strength, lb. per sq. in.....	36,880
Elastic limit, lb. per sq. in.....	14,000
Elongation, % in 2 inches.....	5.7
Reduction of area, %.....	11.6

The increase of tin did not improve the alloy. The color of the fracture was yellowish-gray.

Another sample was then cut from No. 2 gun, and also one from No. 3 gun. These were re-melted and an addition of 0.5% of tin and 1% of zinc was made to each alloy, with the following results:

	No. 2 gun	No. 3 gun
Tensile strength, lb. per sq. in.....	36,000	39,600
Elastic limit, lb. per sq. in.....	12,000	9,200
Elongation, % in 2 inches.....	19.3	16.8
Reduction of area, %.....	24.4	15.2

The color of the fracture of No. 2 was golden yellow and lavender, and that of No. 3 a lavender.

The best mixture of the three was the No. 2 gun, or copper, 90%; and tin, 10%. If the tin is kept at about 9.50% by analysis, this mixture can be depended upon to possess high physical properties, provided it is made carefully and is properly deoxidized. The best deoxidizer to use for this alloy, appears to be 30% manganese copper, using up to 0.5%, as shown by the following tests:

1. Alloy: copper, 90%; tin, 10%; deoxidizer, added as phosphor-copper in place of an equal amount of copper, add-

ing 0.22% of phosphorus: Physical tests of standard test bars, cast-to-size in sand molds were:

	Bar No. 1	Bar No. 2
Tensile strength, lb. per sq. in.....	38,500	35,800
Yield point, lb. per sq. in.....	22,300	21,600
Elongation, % in 2 inches.....	15.5	12.5
Reduction of area, %.....	14.7	18.3

2. Alloy: copper, 90%; tin, 10%; deoxidized with 0.15% phosphorus. This gave the following:

Properties of gun-metal deoxidized with phosphorus

Tensile strength, lb. per sq. in., averaged.....	36,000
Yield point, lb. per sq. in., ".....	23,000
Elongation, % in 2 inches, ".....	10.5
Reduction of area, %, ".....	11.9

3. An alloy consisting of 89.5% copper, 10% tin, and 0.5% of 30% manganese copper, test bars cast-to-size, not machined, gave:

Properties of gun-metal as above

Tensile strength, lb. per sq. in., averaged.....	45,800
Yield point, lb. per sq. in., ".....	21,900
Elongation, % in 2 inches, ".....	24.0
Reduction of area, %, ".....	25.3

When specifications of 40,000 lb. tensile strength with 20% elongation are made, the copper-tin alloy with manganese is the safest to use. The manganese copper must be of the highest grade and contain no iron, otherwise the elongation will materially fall.

It should be added in conclusion to this section on gun-metal that steel has entirely supplanted copper alloys as material for the construction of cannon; nevertheless, great interest attaches to these alloys and the methods formerly employed in making such ordnance.

CHAPTER X

BELL-METAL AND BRIDGE ALLOYS

BELL-METAL

Historical.—Bells are among the most ancient of brass castings; they are common to all peoples and to all climes; and in weight they have ranged from the smallest to the largest castings ever made in any metal or alloy. While bells are not the earliest forms of cast or wrought bronze, they date back to a very early period of human history. The exigencies of life would imperatively demand that weapons be first perfected, but as skill was acquired in the working of metals the industry would branch into other lines of manufacture, and naturally cooking utensils would appear on the scene, and in this connection the claim has been made that the first bells were nothing but cauldrons. These vessels would at first assume a gong-like form, and it would be quickly noted *that* they emitted a loud, musical sound when struck. No doubt the first bells were really gongs, the Chinese to this day being very partial to this instrument. Probably the kettle or cauldron originated the gong, and the drinking vessel of goblet shape became the bell. However this may have been, hand bells have been in use since very remote times by the Assyrians, Babylonians, and ancient Egyptians, and later they were common to the Romans and other nations of that period.

Church bells are supposed to date from about A.D. 400, but it is probable that large bells of similar shape were used in the temples of China and Japan long before this time. The first bells were small—hand bells and small bells for personal adornment—but after being adopted by the Church they began to grow in size and weight, but not with great rapidity, for we find that in the 11th century A.D. the king

presented to the church of Orleans, France, a bell that was then considered remarkable for its size, but its weight was only 2600 lb. If bells were adopted for church use in the first century of the Christian era it required a thousand years for the bell-founding industry to reach a stage of development that made the casting of a 2600-lb. bell a possibility.

Thus, a hundred years in the history of this remarkable industry counts for little, as two hundred years more passed before the size of bells increased to any great extent, and a hundred years more passed after this before really large bells were cast, speaking in a comparative sense. Thus in A.D. 1400, a bell weighing 15,000 lb. was cast in Paris; and 72 years later, another bell was cast in the same city, weighing 25,000 lb. So, in three hundred years the possible weight of these castings increased ten times. It may be remarked in passing, that a 25,000-lb. bell would be no small undertaking for our foundries, even now.

From the 15th to the 17th centuries, bells rapidly increased in size and weight; thus in 1497 a bell weighing 30,250 lb. was cast at Erfurt, Germany. This bell held the European record for size and tone for several years, until in 1501 when a bell was cast at Rouen, France, weighing 36,364 lb. Large bells now became more common, and one in Toulouse, France, weighed 60,000 lb.; one in Vienna, Austria, 56,500 lb.; one in Novgorod, Russia, 70,000 lb.; that at St. Peter's at Rome, Italy, 42,000 lb.; the bell of Notre Dame, Paris, 35,600 lb.; a bell in Milan, Italy, 33,000 lb.; and another in Cologne, Germany, weighed 59,730 lb.

The largest bell in England was that of St. Paul's Cathedral, London, which weighed 39,200 lb. Other notable English bells were one in the Cathedral at York, 24,080 lb.; the Parliament House bell, 34,500 lb.; Great Tom of Oxford, 17,000 lb.; and Great Tom "O" Lincoln, 12,320 lb.

The largest bell in North America is that in the Cathedral of Notre Dame, Montreal, Canada, and weighs 29,400 lb.

Casting the great bell of Moscow.—Probably the largest bells known are those in Russia. Thus the Great Bell, or

Monarch of Moscow, weighed 443,790 lb.—over 220 tons. This bell is one of the largest bronze castings ever made. The mold for this enormous casting was commenced in the year 1732 by John Motorin, foundry foreman of the Russian Royal Gun Factory. Associated with him in the work were five men, whose names have come down to us as Cobeloff, Galkin, Cogtef, Scriebriakoff, and Loukovnikoff. In January, 1733, nearly 100 workmen were engaged in constructing the mold, the work continuing until November 26, 1734. By this time the mold was ready to cast, being thoroughly dry and secured. Four reverberatory furnaces were to be used for melting the metal, the first charge for which amounted to 196,028 lb. The fires were started at 4 P.M., and in the night the metal commenced to melt. The next day—November 27th—189,936 lb. more metal was added, and on the day following, 72,000 lb. of copper and tin were added. All went well until 11 P.M., of that day, when two of the furnaces gave way, and 234,000 lb. of metal was lost. At 1 P.M. on the 29th, some old bells were taken from the arsenal and the metal was added to the other furnaces. This charge consisted of about 600 bells weighing 59,268 lb., and from the gun factory 148,832 lb. of small copper coin, and 10,800 lb. of tin were obtained and charged into the furnaces. This amount of tin being considered insufficient, the records state, “they sent down town and bought 400 pouds [14,000 lb.] more tin.” At 7 A.M. of the 29th, the two other furnaces gave way, and all the bronze went through the bottom into the ground, and the heat was so intense the crane took fire, and the entire building burned down; but the mold was not destroyed, although it became wet. John Motorin died during the next year, probably from worry and anxiety, and left the work to his son, who had assisted him from the start. The son took up the work with determination to succeed, and on November 23, 1735, the furnaces were ready again; and profiting by the two former mishaps, the bell was successfully cast two days later. The inscription on the bell gives 1732 as the date of casting, but merely means the mold was made

in that year. The cost of making the bell, exclusive of the metal, was \$47,770.

The dimensions of the bell are: height, $19\frac{1}{4}$ ft.; circumference, $60\frac{3}{4}$ ft.; thickness of the walls at the thickest part, 24 in., and at the thinnest part 6 in. By the spring of 1737 the bell had been cleaned, but was still in the casting pit and stood on an iron grate which probably had been a part of the mold. The casting pit was walled with logs to prevent the earth caving, and on May 29, 1737, a terrible fire occurred in Moscow, and the cranes and the building over the bell were burned down. The logs forming the walls of the casting pit took fire, creating an intense heat around the bell, and the metal cracked in eight places, probably on account of unequal expansion, and one piece, 7 ft. wide and high, weighing 10 tons, broke out. The analysis of the metal in the bell is as follows: Copper, 84.51%; tin, 13.25%; and sulphur, 1.20%; with traces of silver, zinc, and arsenic.

After the fire, the bell still remained in the ground, and it was not until 1836 that the pit was cleaned out and the bell was once more exposed to view, after being buried for a hundred years in the pit in which it was created. The depth of the pit was 30 ft., and 2 months were occupied in getting the bell ready to be raised. On July 23, 1836, the actual lifting was started, and in 43 minutes the bell reached the level of the ground for the first time in its history. It was moved 40 ft. from the casting pit, and placed on a granite foundation, the work being finished August 4, 1836, nearly 101 years from the day it was cast.

The Liberty Bell.—The most notable bell in the United States is the Liberty Bell. This famous bell was brought from England, and the first time it was struck when tested, it broke. This was in August, 1752, after which it was then broken up and was re-cast by Pass and Stow of Philadelphia. Copper was added to the second bell to toughen it, with the result the tone was ruined, and the discordant note of the bell caused so much criticism that the bell-founders asked permission to re-cast it again; and the result of their work was

the present bell, the tone of which was never satisfactory, it being described as a "loud and harsh clamor." When tolling on the occasion of the funeral of John Marshall, formerly

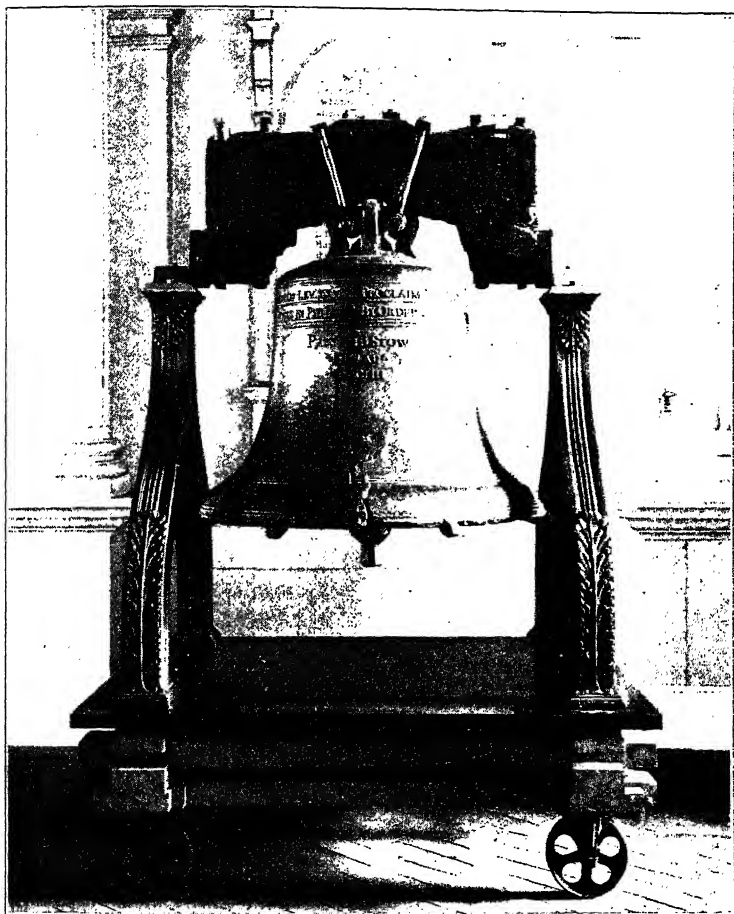


Figure 56.—The Liberty Bell.

Chief Justice, it cracked, and the crack has been slowly extending ever since. Figure 56 shows the bell as it appears at present in Independence Hall, Chestnut Street, between South Fifth and South Sixth Streets, Philadelphia, Pennsylvania. The bell hangs from its original beam within an ornamental

frame, and is exhibited in the main corridor where it may be closely examined, but is carefully guarded. The bell was ordered by the Superintendent of the State House in Philadelphia from the agent of the Province in London, England. The requirements were that it should weigh about 2000 lb., and bear inscriptions as follows:

By order of the Assembly of the Province of Pennsylvania for the State House in Philadelphia, 1752,

and underneath,

Proclaim Liberty throughout all the land unto all the inhabitants thereof, Lev. XXV, V, X.

Figure 57 is a "close-up" of the top of the bell, and illustrates how the crack was spreading, and would ultimately have caused the bell to break into pieces if this danger had not been safeguarded against as shown in figure 56. This illustration also shows the porosity of the metal in the bell.

There are many large bells in China and Japan, but details regarding them are lacking. The Great Bell of the Chion-in temple in Kyoto is a notable example. The shape of these bells differed materially from those of Occidental countries, but the Japanese bells gave out a deep melodious sound, while some Chinese bells emitted a discordant sound, which is supposed to have been intentional.

Bells not only vary in size, but also in shape; thus the sleigh bell is globular in shape; the cymbal is a circle with a cup-shaped depression at the center; and the bell proper resembles an inverted goblet with flaring mouth.

Modern casting of small bells.—Sleigh bells are made in large numbers in East Hampton, Connecticut. They are molded, 30 bells in a mold with the slotted opening downwards, in a three-part flask or its equivalent. Being globular, the parting line of the mold has to be made at the equator of the bell, and they are gated on top of the flat, suspending lug, the metal being thus dropped into each bell cavity. It will be noted, therefore, that the runners are in the cope; the upper halves of the gate of bells are in the cheek; and

the lower half with core prints in the drag. The metal is carried to the casting spaces by five parallel runners connected at their centers into a grid by a main runner on top of which is the pouring sprue. Each runner connects to six bells—three on either side the main runner—which is at right angles to the length of the distributing runners placed in parallel. Before being melted, the metal is simply scrap yellow brass—old clock works and such like, containing iron.

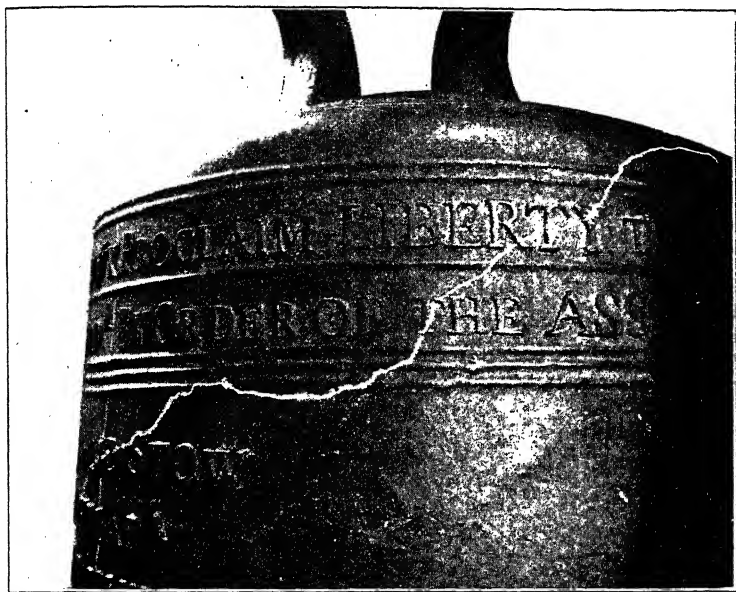


Figure 57.—Crown of the *Liberty Bell*.

This metal is melted in small temporary furnaces, which are really small cupolas, consisting of a receptacle for the metal, which can be used as a ladle for pouring the molds, and a "shaft" which is merely a boiler iron cylindrical shape, like a letter U with the open ends bent over. This shell is fitted with a retaining ledge at the bottom, and is lined with fireclay. It is set on top of the ladle, the latter being a bowl-shaped affair with an attachment to which a long handle can be fitted. The ladle is lined with loam and is bedded in the

floor, near to a wall through which a blast tuyère protrudes at a height a little above the top of the ladle. The lined shell with its open side is placed on the ladle—the opening next the wall where the tuyère protrudes—the charcoal is shoveled in and lighted; the blast is turned on, and the shell is filled with charcoal. When this is well alight, a shovelful of metal is put on top. Any kind of metal can be used, and if it does not contain iron, this is added in the shape of a small piece of cast iron, which is thrown on top of the coals. When the metal is all melted, and the operator considers it hot enough, the clay-lined sheet-iron stack is lifted away, and by this time most of the charcoal has disappeared, so the ladle with the metal therein can be skimmed and carried away to the molds. A long wooden handle is attached to the ladle, and a strap is snapped to the handle and passed around the neck of the man pouring off to help support the burden. This simple furnace converts brass residues, such as clock works, skimmings, and other material containing gangue and iron, into clean red brass, producing castings clean and bright in appearance, and containing no unalloyed iron. A hood or chimney is necessary to carry away the fumes. According to Sperry, one man will readily obtain seven heats a day of about 60 lb. of molten metal per heat, about 420 lb. per man, and make his own molds also.

A mold for a locomotive bell is shown in figure 58, in vertical section from corner to corner, which will serve to illustrate the usual method of molding this object. It will be noted that a three-part flask is used. The drag carries the core of the bell, which is of green sand. Ordinarily, such bells are poured "two up," from opposite corners of the mold, as shown. These bells weigh in the neighborhood of 100 lb. each, and the gates are cut into the sound bow. The core is shown staked, to prevent its floating. Frequently this is all that is done, although this method might be improved upon. It is necessary to use a free venting sand—not too fine—otherwise the surface of the bell, especially at the sound bow, will be scabbed as the mold has to be rammed fairly hard

at this point; otherwise the bell metal, being of a very searching nature, will eat into the sand, and also cause the bow to come lumpy. When the sand is of the correct grade, the cheek of the mold properly rammed, and the core well vented and secured, this method produces good castings. The mold must be well clamped, and the joint between cheek and drag must be perfect, otherwise the mold will spring open while

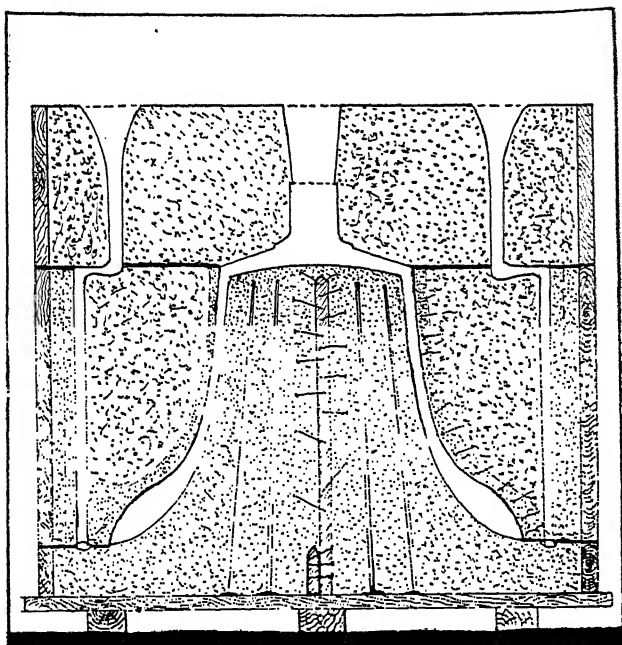


Figure 58.—Vertical section of mold for locomotive bell.

being poured, owing to the pressure of the metal. Locomotive bells are sometimes made of steel, but the bronze bell has a much superior tone and is extensively used. The bells crack easily in zero weather, which is a drawback to the use of regular bell metal.

If the castings come porous, as frequently happens, the best deoxidizer to use is iron; but it must be added as yellow prussiate of potash or soda. Iron eliminates gas-holes and also improves the tone of the bell; phosphorus should never

be added to bell metal which is to be used for its musical note. For locomotive and small ship bells, an excellent formula to use is 80% copper and 20% tin. Melt the copper in graphite crucibles, and when it begins to sink down, add a flux consisting of 1 lb. of yellow prussiate of potash, 1 lb. of silica sand, 1 lb. of soda ash, and 4 oz. of calcined borax. Place plenty of charcoal in the pot with the copper, and when it begins to melt, put in the flux. When the copper is liquid, stir in the flux, then add the tin, stir again, remove from the furnace, and pour. An analysis of a bell made by using this flux showed an iron content of 0.46% according to Sperry.

Cymbals are made of an alloy composed of 78% copper and 22% tin. These castings are difficult to make, as they are circular plates 12 to 15 inches in diameter, and from $\frac{1}{8}$ to $\frac{3}{16}$ inch thick. They have a dished center, and are sometimes run by molding them with the convex side in the cope, and gating by means of several drop gates not thicker than a lead pencil, which are grouped on the humped part. Cymbals must be tempered after they are cast to eliminate the brittleness, which is done by quenching from a red heat. It is of course necessary to support these castings while they are being heated and quenched, otherwise they would fall to pieces. This can be done by clamping them between plates of iron shaped like a mold for the castings.

Silicon in bell-metal.—Silicon is sometimes used in ordinary bell-metal. An addition of 1% of silicon copper to the bronze used for cymbals will ensure the castings running, but will do no harm to the tone. The action of silicon is much the same on bell metals as that of aluminum in the case of yellow brass—it renders the metal more fluid and prevents its burning into the sand, and smoother and cleaner castings result from its use in this manner.

Characteristics of bell-metal.—Bell-metal must be hard to give a sound and not suffer a change in form when the bell is subjected to the frequently repeated action of the clapper or tongue. It must therefore contain more tin than gun-metal; but notwithstanding the high tin content it should not

be more brittle than can be helped so as not to crack under these strains. For this reason, the addition of other metals; besides copper and tin, is not good practice—in fact, it is useless and in most cases injurious. Experience has shown that the best proportion of the two constituent metals is 20 to 23 parts tin to 77 to 80 parts copper. The quantities of incidental foreign constituents present—such as zinc, iron, and nickel—will of course be the greater, the more impurities are contained in the two metals used, and will therefore appear, as a rule, in greater abundance in old than in new bells. In some bells up to 1% of silver has been found, the opinion being formerly held that an addition of silver adds to the beauty of the sound, though from what has been previously said, it will be understood that such is not the case.

Structure.—Bell-metal is brittle and cracks under the hammer—cold as well as heated. If it be repeatedly brought to a dark-red heat and quickly cooled by immersion in water, its brittleness is so far reduced that it can be hammered and stamped. The color of good bell-metal is a peculiar gray-white, differing materially from that of gun-metal and statuary bronze. The bell-founder judges the correct composition of the bell-metal by the appearance of the fracture; if the latter is too fine-grained the alloy is too rich in tin; if too coarse-grained it contains too little tin. The fracture is generally fine-grained and of a gray color. This is due to the brittleness of the whitish mixture rich in tin, which more and more predominates and almost exclusively forms the surface of the fracture. The structure is distinguished from that of gun-metal by the predominance of dendritic formations. It is scarcely possible to find on the ground surfaces traces of network—aggregates of crystals resembling fir-tree branches appearing almost always—calling to mind by form and fineness chilled 10% bronze, but of a pale-yellow color, and separated by an abundance of an intermediary substance of a grayish or whitish color.

Independent of the quality of the material used, the tone of a bell depends materially on its size and form, the thick-

ness of the walls and the proportion of height to diameter being also of importance for a beautiful and pure tone. The skill of the bell-founder lies not so much in finding the correct composition of the alloy—this being thoroughly understood at the present time—as in giving the bell a shape corresponding to a certain tone, which is of special importance for chimes.

Melting and casting bell-metal.—The melting and casting of bell-metal is not so difficult as that of ordnance bronze, though great similarity exists between them. The copper is first melted down, and after heating the fused mass as much as possible, the tin is introduced and an intimate mixture is promoted by vigorous stirring. Many bell-founders do not add all the tin at one time, but about two-thirds of it at first, and when this has formed a union with the copper, the other third is added.

It rarely happens that only new metals are used in preparing the bell-metal, old bells and ordnance bronze being worked in large quantities. The composition of these should, however, be known, so that the mean of the alloy will be such as to yield a bell of the required quality. For this purpose it is best to melt small portions of the respective metals together in the same proportions in which they are to be fused on a large scale. From the quality of these test-pieces it will then be seen whether a change in the composition of the alloy is necessary.

It is still more preferable to ascertain the composition of the metals by chemical analysis, as the appearance of the fracture, color, and degree of brittleness may give rise to error.

It has been frequently observed that bells repeatedly remelted acquire a disagreeable tone. The principal reason for this change is found in the solution of oxide in the alloy. This evil can be overcome by deoxidizing the mixture of metals, to which we will refer later on. While the composition of bell-metal for large bells is always within the above-mentioned limits, the material used for the manufacture of

small tower bells, table bells, and the like, varies considerably; mixtures being often used which actually cannot be classed as bell-metal, they being frequently only tin alloyed with a small quantity of copper and a little antimony.

Composition of bells.—The following table shows the composition of some bell-metals:

TABLE 26.—*Composition of certain bells (per cent)*

	Copper	Tin	Zinc	Lead	Silver	Iron
Normal composition.	80	20				
	78	22				
Alarm bell at Rouen.	76.1	22.3	1.6	.....	1.6	
Alarm bell at Ziegenhain. . .	71.48	33.59	.....	4.04	.....	0.12
Alarm bell at Darmstadt. . .	73.94	21.67	.....	1.19	0.17	
Alarm bell at Reichenhall (13th century).	80	20				
Tam-tam.	78.51	10.27	.....	0.52	0.18	
	10	4	1.5	.....	0.5	
Bells of Japanese origin. . .	10	2.5	0.5	1.33		
	10	3	1	2	0.5	
	10					

For small clock bells, table bells, sleigh bells, etc., an alloy giving a clear and pure tone must be used, and experience has shown that bell-metal with about 22% of tin gives the finest tone, and can therefore be suitably used for small bells. The following table will suffice to show the composition of such alloys:

TABLE 27.—*Composition of small bells (per cent)*

	Copper	Tin	Zinc	Lead	Silver	Anti- mony	Bis- muth
House bells.	80	20					
House bells, smaller.	75	25					
Clock bells, German.	73	24.3	2.7				
Clock bells, Swiss.	74.5	25	.....	0.5			
Clock bells, Paris.	72.0	26.56	.....	.....	1.44		
Sleigh bells.	84.5	15.42	.....	.....	.....	0.1	
White table bells.	17	80	.....	.....	.....	.....	5
White table bells. . . . .	.....	7	.....	.....	.....	1	

Chinese tam-tams or gongs are distinguished by a strong, far-reaching sound. The alloy of which they are made consists in general of 80 parts copper and 20 parts tin. Genuine Chinese tam-tams are made, as shown by their appearance, from a thicker block of metal by forging with the hammer. However, bell-metal of the composition mentioned is brittle at ordinary temperatures as well as at bright red heat, and its brittleness is but slightly decreased by tempering. The secret of the manufacture of tam-tams is found in the property of these alloys to become suddenly malleable at a perfectly dark-red heat, but to lose this malleability rapidly at higher, as well as lower, temperatures.

Algiers metal (metal d'Alger) has a nearly pure white color and takes a beautiful polish. It can scarcely be classed with bell-metal, its composition—copper, 5 parts; tin, 94.5 parts; and antimony, 0.5 part—having nothing in common with it. The antimony is most likely added to give greater hardness.

Large bells are cast in loam molds. The figures or designs with which the bell is to be ornamented are placed in the mold, the portions which have been left imperfect in casting being dressed after the cast bell is cold. Small bells are generally cast in sand molds, though iron molds are frequently used.

Silver bell-metal, an alloy suitable for small bells, is distinguished by a beautiful silver-clear tone, and a nearly white color. It is composed of 40, 41.5, or 41.6 parts of copper, and 60, 58.5, or 58.4 parts of tin.

As previously stated, the properties of bronze may be varied within very wide limits according to the purpose for which it is to be used. A few of the most important bronzes used in the various branches of industry are here given. To enter on a detailed description of all these alloys is scarcely practicable, since many manufacturers preparing bronzes for their special purposes use alloys which, as regards their percentage composition (in respect to copper and tin), show considerable variations; and sometimes contain other metals as

additions, which, according to the assertions of the manufacturers, impart to them exactly the properties desired.

BRIDGE ALLOYS

Any alloy of copper and tin containing more than 18% of tin can properly be termed a bell-metal. Such alloys are both hard and brittle, and are the alloys of highest tin content in regular use. The next hard series of alloys are the bronzes used in turntables and movable bridges as pivots upon which the structure revolves. These bearings are bronze discs, which turn between two hardened steel discs. Both steel and bronze discs may be round and flat, or the bronze may be lenticular in section and the steel discs may be concave. The lower steel disc is fixed to the support upon which the bridge pivots; the upper steel disc is attached to the bridge turntable, and the bronze disc is loose between them, but confined against sideways slip. The bronze is therefore ground between two hardened steel discs under enormous pressure, and this naturally requires a very hard bronze, which at the same time must not be too brittle.

The discs in turntables will range from 14 to 24 inches in diameter, and the pressure from 1500 to 3000 lb. per sq. in. when the table is being turned with a locomotive on it, according to O. E. Selby, in a paper read before the Institute of Metals (*Journal*, vol. XI, 1917, No. 3, pages 359-369). The center-bearing swing-bridge has a disc as high as 42 inches in diameter; bascule and lift bridges require bronze-lined trunnion bearings of great size. These trunnion bearings have a slow motion, and lubrication is difficult. Table 28 contains specifications for alloys for these purposes made by the Committee on Iron and Steel Structures of the American Railway Engineering Association in 1914.

Grade A is to be used for contact with hardened steel discs under pressures exceeding 1500 lb. per sq. in., such as are used in turntables and center-bearing swing-bridges. Grade B is to be used for contact with soft steel at low speeds under pressures not exceeding 1500 lb. per sq. in., such as

trunnions and journals of bascule and lift bridges. Grade C is to be used for ordinary machinery bearings. Grade D is to be used for gears, worm-wheels, nuts, and similar parts which are subjected to other than compressive stresses.

TABLE 28.—*Specifications for bridge alloys*

	GRADE			
	A, per cent	B, per cent	C, per cent	D, per cent
Copper (approx.).....	80	85	80	88
Tin (approx.).....	20	15	10	10
Lead (approx.).....			10	
Zinc (approx.).....				2
Phosphorus (max.).....	1	1	1	0.25
(min.).....			0.7	
Other elements (max.).....	0.5	0.5	0.5	0.5
Elastic limit in compression, lb. per sq. in. (min.)..	25,000	19,000	15,000	14,000
do. (max.)..	40,000	23,000	20,000	.....
Permanent set, under 100,000 lb. (min.)	0.06	0.12		
do. (max.)	0.01	0.25		
Ultimate strength in tension, lb. per sq. in. (min.).....				33,000
Elongation, % in 2 inches (min.).....				14

Grade A bridge bronze is used for bells, bearings, dies, and discs for draw-bridges and turntables. Its composition should be about 80% copper, and 20% tin, with a trace of phosphorus for all purposes except bells, when iron should be used instead as a deoxidizer, as it gives improved tone. The following tests in compression are given by the American Bridge Co., using an alloy composed of 83% copper, 17% tin, and 0.05% phosphorus:

Compression tests of bridge bronze

Test No.	Elastic limit under compression, lb.	Permanent set under a load of 100,000 lb., inch
1	23,560	0.168
2	21,630	0.168
3	23,500	0.168
4	24,000	0.152
5	25,750	0.119
6	23,430	0.165

The following examples of alloys made by the author of this volume will serve as a guide in deciding on the amount of tin to use for alloys to meet compression specifications:

Tin content and tests of certain bridge alloys

Alloy No. 1	Lb.	Oz.	Results
Copper.....	83	2	Elastic limit under compression,
Phosphor copper...	0	6	lb..... 24,000
Tin.....	16	8	
	100	0	Permanent set under load of
			of 100,000 lb., inch..... 0.136
Alloy No. 2	Lb.	Oz.	Results
Copper.....	82	14	Elastic limit under compression,
Phosphor copper...	0	6	lb..... 25,000
Tin.....	16	12	
	100	0	Permanent set, under load of
			100,000 lb., inch..... 0.126
Alloy No. 3	Lb.	Oz.	Results
Copper.....	82	10	Elastic limit under compression,
Phosphor copper...	0	6	lb..... 26,000
Tin.....	17	0	
	100	0	Permanent set under load of
			100,000 lb., inch..... 0.116

SUNDRY BRONZES

Medal and coin bronze.—A bronze suitable for these purposes must have a certain degree of ductility, so as to be able to receive a true impression and wear well. In many countries the baser coin is now made of a bronze-like alloy instead of pure copper as formerly, it being better able to resist abrasion and injury resulting from circulation. The bronze used in casting medals contains a variable proportion of tin, generally ranging from 4 to 10%, according to the depth of the impression. Bronzes containing about 8% of tin are distinguished by great hardness, but can be rendered sufficiently soft for stamping by heating to a red heat and tempering. This variety of bronze is chiefly used for medals, which besides being distinguished by artistic execution, must have considerable durability. If the impression is to be fairly deep, or if the medals are to be stamped several times, they must be repeatedly annealed.

An addition of a very small quantity of lead and zinc has a favorable effect upon the metal to be used for medals, as they render it softer, so that it can be worked with greater ease, and its color and fusibility are also improved.

The baser coin of many countries consists of a bronze of varying composition. For instance, the copper coin manufactured in France since 1852 consists of 95 parts of copper, 4 parts of tin, and 1 part of zinc. This alloy has stood the test of time, coins stamped in that year still showing the impression in all its details, which is sufficient proof of its durability. Coin bronze as made by the Greeks and Romans contained from 96 to 98 parts of copper and 4 to 2 parts of tin. Chaudet has shown that the first of these alloys can be used for fine work, medals of this composition taking a perfect polish while sufficiently hard to wear well.

Many medals, as is well known, do not show the color of bronze, but a pleasant brown, subsequently produced by oxidation. A bronze, which, on account of its pale-red color is especially adapted for medals with figures in high relief, consists of a mixture rich in copper. It is at the same time very flexible, so that the medals can be stamped without an expense of great power. This bronze consists of 97 parts copper, 2 parts tin, and 1 part lead.

Medals whose size does not exceed a certain limit are at present stamped from sheet rolled out to the required thickness, and the blanks thus obtained stamped with the impression, this method being also used in making coins. For large medals with impressions in high relief, plates are prepared by casting, the model of the medal being used in order to obtain plates already somewhat raised or depressed on the respective places. As soon as the pieces cast in sand are solidified, they are thrown into cold water to give them the required degree of softness. After subjecting them to one or two passes in the stamping-press, they must be again annealed in order to prevent cracking of the edges.

Speculum metal.—Alloys composed of two-thirds copper and one-third tin take a beautiful polish, and can be used as

mirrors. At the present time such alloys are only used in the construction of mirrors for optical instruments, especially for large telescopes, though they are being gradually displaced by glass mirrors.

Good speculum metal should be perfectly white, without a tinge of yellow, with a fine-grained fracture, sound and uniform, and sufficiently tough to bear the grinding and polishing without danger of disintegration. A composition answering all purposes must contain at least 65 to 66% of copper. The specula made by Mudge contained from 32 parts of copper and $14\frac{1}{2}$ to 16 of tin. A little tin is lost in fusion. It has been frequently attempted to increase the hardness of this metal by adding arsenic, antimony, and nickel; but with the exception of nickel, these additions have, however, an injurious effect, the specula readily losing their high luster, this being especially the case with a larger quantity of arsenic. According to Bischoff, a mirror composed of 66.3% copper, 32.1% tin, and 1.6% arsenic, which possessed a white color and excellent luster, after some time suddenly tarnished and became coated with a green patina. Sollitt claims that an addition of arsenic during fusion prevents oxidation of the tin.

It would seem that the actual speculum metal is a combination of the formula Cu_4Sn , and has the composition of copper, 66.6%, and tin, 33.4%.

According to David Ross the best proportions are: copper, 126.4 parts, and tin, 58.9 parts. He added the molten tin to the fused copper at the lowest safe temperature, stirring carefully, and securing a uniform alloy by re-melting.

Tin spots.—The so-called tin spots, which sometimes separate when ordnance bronze is incorrectly treated, form an alloy similar in composition to speculum metal. It has, however, not a pure white color, such as is found in those containing 31.5% of tin. By increasing the copper content, the color shades gradually into yellow, and with a large amount of tin, into blue. It is risky to increase the tin content too much, as besides the change in color, the alloy becomes brittle

and can not be worked further. The following table shows the composition of some alloys used for speculum metal: (It may, however, be remarked that the standard alloy is undoubtedly the best for the purpose.)

TABLE 29.—*Composition of alloys used as speculum metal (per cent)*

	Copper	Tin	Zinc	Arsenic	Other metals
Standard alloy.....	68.21	31.79			
Otto's.....	68.5	31.5			
Richardson's.....	65.3	30	0.7	2	2 silver
Little's.....	65	30.8	2.3	1.9	
Sollit's.....	64.6	31.3	....	....	4.1 nickel
Chinese speculum metal.	80.83	....	....	....	8.5 antimony
Old Roman.....	63.9	19.05	....	....	17.29 lead
Sundry alloys.....	32.00	16.50	....	1.25	4 brass
“ “.....	32.00	15.50	....	2.00	
“ “.....	32.00	15.50	....	....	2 nickel

Mirror alloys.—According to Boedicker, the mirror of the celebrated Ross telescope, which has a diameter of 6 feet and weighs 11,000 lb., is composed of copper, 70.24%; tin, 29.11%; zinc, 0.38%; iron, 0.10%; lead, 0.01%; and nickel, 0.01%.

For the manufacture of concave mirrors an alloy of 18% each of copper, tin, and zinc, 36% of nickel, and 10% of iron, has been recommended.

The composition of a few recent and old bronze mirrors are given below:

Composition of bronze mirrors

Name	Weight, lb.	Copper, %	Tin, %	Iron, %	Lead, %
Telescope mirror at Birr Castle, Ireland.....	11,000	70.24	29.11	Traces	
Mirror at Brunswick, Germany.....	.....	65.1	32.8		
Roman mirror at Mayence.	.....	63.4	19.0	.....	17.3
Old Egyptian mirror.....	.....	85.0	14.0	1.0	

Chinese metal mirrors, probably the so-called "magic mirrors," * contained antimony and lead, as well as copper, for example: 80.8% copper, 8.4% antimony, and 9.7% lead. This metal, therefore, cannot be designated as bronze in the actual sense of the word.

* Figures or inscriptions cast upon the back of such mirrors appear more or less plainly in the light reflected from the front. Thicker places—in this case the figures on the back—turn out porous in casting and being more firmly pressed together by the subsequent grinding and polishing, reflect the light differently from the thinner parts. Such mirrors can also be made from other copper alloys.

CHAPTER XI

PHOSPHOR AND SILICON BRONZES

PHOSPHOR-BRONZE

Definition.—In the actual sense of the word, phosphor-bronze cannot be considered as an alloy containing a fixed quantity of copper, but rather a bronze subjected to a peculiar treatment by means of certain combinations of phosphorus.

It has been previously mentioned that bronze frequently contains a considerable quantity of cuprous oxide in solution, which is formed by direct oxidation of the copper during fusion, and that the admixture of this oxide to a great extent impairs the strength of the alloy. If the melted bronze be treated with a substance exerting a powerful reducing action, such as phosphorus, a complete reduction of the cuprous oxide takes place, the pure bronze acquiring thereby a surprisingly high degree of strength and power of resistance. If the exact quantity of phosphorus required for the complete reduction of the oxide has been used, no phosphorus will be found in the alloy, but the latter must nevertheless be called "phosphor-bronze." Hence, it will be readily seen that phosphor-bronze is not a special alloy, but that every kind of bronze can be converted into it, and by using combinations of phosphorus, phosphor-bronze is therefore deoxidized bronze.

Phosphor-bronze has long been known to chemists, but its valuable qualities as a material to be used in construction were first made known by Montefiori-Levi and Künzel, who discovered the alloy in 1871.

Adding yellow phosphorus.—The first additions of phosphorus were made to bronze by dissolving the elemental yellow stick phosphorus in the molten metal. This procedure is attended with considerable danger owing to the flammability of the phosphorus, also to it being necessary to store it under

water. The phosphorus cannot be removed from the water and dried; it must be carried to the furnaces, or to the crucible of molten metal when the latter has been "pulled," in a can of water; and when it is thrown onto the surface of the bronze it is wet, and knowing by experience the danger attending the introduction of wetted objects into molten metal, the furnaceman has an instinctive desire to dry the stick of phosphorus by rolling it on his heated overalls, with the result that the chemical becomes inflamed and inflicts serious burns. This has occurred many times, therefore it is better to safeguard the workers against such accidents by using the rich phosphorous-copper or phosphorous-tin alloys instead of the element itself. These alloys are made by specialists to standard percentages of phosphorus, who get expert in handling the dangerous chemical, and are able to make the alloys with little danger, and by making them in large quantities, can sell them at a reasonable price; so that, aside from all considerations of the danger of setting fire to the foundry, and injuries to employees attending the use of stick phosphorus, it is not economical to use it.

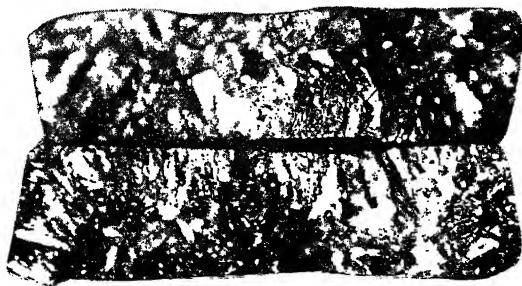


Figure 59.—Fractures of phosphor-tin.

Phosphor-tin.—This is the alloy or admixture of phosphorus and tin which contains as a standard alloy, 5% of phosphorus, and the remainder tin. It should contain no lead, and when made by a reputable maker it can be depended upon as being lead-free. In appearance, the fractured surfaces of 5% phosphor-tin is not unlike that of antimony, its showing large, glittering crystals, as shown in figure 59.

TABLE 30.—Results of the mechanical and chemical tests of phosphor-bronze

No.	Character of sample	Chemical analysis					Ultimate tensile strength, in tons per sq. in.	Elongation on 2 inches, %	Elongation on 6 inches, %	Results of bending tests	Remarks
		Copper	Tin	Lead	Zinc	Phosphorus						Total
1	Casting.....	82.3	10.8	6.25	None	0.54	99.89	15.3	12		
2	Bearings.....	84.5	14.5	None	"	0.86	99.86	7.76	1		
3	Casting.....	85.1	14.3	"	"	0.69	100.09	14.56	5		
4	Piston packing ring.....	85.6	10.8	"	2.74	0.82	99.96	8.5	3		
5	Casting.....	86.4	13.0	"	None	0.51	99.91	14.55	2		
6	"	86.6	12.9	"	"	0.41	99.91	14.04	5		
7	Gear Wheel.....	86.8	12.2	"	Trade	1.43	99.43	13.4	4.5		
8	"	87.0	12.0	"	"	1.56	100.56	13.94	7		
9	Piston packing ring.....	87.2	11.2	{ under 0.3	1.3	None	99.70	18.0	15		{ Phosphorus too low
10	Spanner.....	87.3	12.2	None	None	0.10	99.60	13.69		9.3	{ Broke when bent 45°
11	Sheaves.....	87.4	11.1	"	"	0.49	98.90	18.02	10		
12	Bushes.....	87.6	11.2	"	"	0.53	99.33	20.8	18.75		
13	Sheaves.....	87.7	10.5	"	1.39	0.35	99.95	18.96	15		
14	"	87.8	8.8	3.3	None	0.33	100.23			5	Rejected on account of lead
15	Piston packing ring.....	87.7	10.7	None	"	0.97	99.37	23.2	6		
16	Sheaves.....	88.1	10.5	"	"	0.42	100.02	18.23	12		
17	Boat hoist fittings.....	88.2	10.5	"	"	0.51	99.21	17.8		18	Satisfactory
18	Sheaves.....	88.2	8.8	3.2	"	0.24	99.56	12.7		5	Rejected on account of lead
19	Block.....	88.5	10.5	None	"	0.16	100.00	15.84		3	Complete article tested to 10 cwt.
20	"	88.4	10.1	"	1.34	0.16	99.70	15.6			
21	Casting.....	88.2	11.2	"	None	0.30	99.70	24.2	12.5		
22	Worm wheel rim.....	88.7	10.4	"	0.58	0.33	100.11	16.4	34.5		
23	Casting.....	88.9	10.2	"	None	0.68	99.80	11	10.4		
24	Worm wheel rim.....	88.8	10.8	"	"	0.07	99.67	{ 14.8 & 8.66	10 & 3		{ Phosphorus too low. Duplicate mechanical tests made. Rejected
25	Casting.....	88.8	10.3	"	"	0.67	99.77	16.4	11		
26	Capstan gear.....	88.9	9.9	"	0.7	0.40	99.90	15.7	15		
27	Bearing.....	88.9	10.1	"	None	0.82	99.72	18.8	10		
28	Winch casting.....	88.8	11.0	"	"	0.52	100.42	15.5	12		
29	Bush.....	88.9	10.3	"	"	0.77	99.97	19.0	10.5		
30	Sheaves.....	88.5	10.8	"	"	0.20	99.60	18.2	12		
31	"	88.2	10.3	"	"	0.58	99.58	17.32		6.5	
32	"	88.4	10.3	"	"	0.38	99.08	15.5		16.1	

TABLE 30.—Results of the mechanical and chemical tests of phosphor-bronze—Continued

No.	Character of sample	Chemical analysis					Ultimate tensile strength, in tons per sq. in.	Elongation on 2 inches, %	Elongation on 6 inches, %	Results of bending tests	Remarks
		Copper	Tin	Lead	Zinc	Phosphorus	Total				
68	Sheaves.....	90.4	8.9	None	None	0.73	100.03	18.5 & 20	24 & 26	.....	{ The mechanical tests were made in duplicate
69	"	90.2	9.6	"	"	0.22	100.02	17.8 & 16.3	7.8	.....	do.
70	"	90.4	9.2	0.1	"	0.45	99.95	22.9	31.2	.....
71	Gear wheel.....	90.5	9.5	None	"	0.08	100.08	23.8	54.0	.....
72	Casting.....	90.0	9.6	"	"	0.42	100.02	13.0	7.5	.....
73	Sheaves.....	90.3	8.7	"	"	0.15	100.15	16.8 & 17.5	.....	22.9 & 21.8	{ The mechanical tests were made in duplicate
74	Bearing.....	90.6	8.4	"	"	0.53	99.53	21.0	.....	.....
75	"	90.9	8.4	"	"	0.37	99.97	19.2	21	.....
76	"	90.5	8.9	"	"	0.42	99.82	20.3	20	.....
77	Sheaves.....	90.4	8.7	0.18	"	0.53	99.81	17.5	22	.....	Satisfactory
78	Bush.....	90.9	8.3	None	"	0.46	99.66	20.1	30	.....	Satisfactory
79	Sheaves.....	91.3	8.5	"	"	0.37	100.17	18.4	.....	16	Bent 90° did not break
80	Bush.....	91.3	8.2	"	"	0.45	99.95	20.1	30	.....	Satisfactory
81	Spindle.....	91.3	9.0	"	"	0.29	100.59	16.9 & 18.8	16 & 25	.....
82	Sheaves.....	92.3	7.2	"	"	0.42	99.92	24.3	50	.....
83	Elec. motor fittings.	93.9	5.6	"	"	0.58	100.08	22.4	18.5	.....	Satisfactory
84	Bushes.....	94.4	5.2	"	"	0.45	100.05	16.6	20.0	.....
85	Worm wheel rim.....	94.2	4.9	"	"	0.96	100.06	25.0	28.0	.....	Satisfactory
86	"	94.4	4.8	"	"	0.98	100.18	24.8	36.0	.....	Satisfactory

NOTE.—"Satisfactory," under bending test, means that the sample bent without cracking or breaking through 180°.

Phosphor-copper.—This alloy may have either 10 or 15% of phosphorus, and while the latter mixture is mostly preferred the 10% mixture is the more dependable, as this amount of phosphorus can be obtained in solution with copper without difficulty; therefore it is preferred in cases where the phosphorus content must conform to rigid specifications. Phosphor-copper can be obtained either in flat, notched ingots, or in the form of a shotted product.

A complete and valuable paper on phosphor-bronze was presented by A. Philip, Admiralty chemist, before the Institute of Metals,* England, from which we abstract table 30.

The condition in which phosphorus exists in phosphor-bronze is explained as follows by Philip:

If sections of samples of phosphor-bronze containing from 0.1 to 2.0 parts of phosphorus are polished and examined under the microscope—without etching or coloring in any way—by means of vertical illumination it will be noticed that as the phosphorous content rises, a network of pearly-gray color can be distinguished in increasing amounts clearly outlined against the redder color of a copper-tin alloy. This effect, although readily apparent to the eye, is not easily photographed, and it is considered that for uniformity of examination it is desirable to as far as possible avoid the use of etching or coloring effects. The difference in apparent color between the grayer and the redder constituents is very much like that seen when the disc of the full moon is seen low on the horizon, the markings on the moon contrasting with its reddish, higher lights in very much the same tints. It is considered that when phosphor-tin or phosphide of copper is added to copper or to a copper-tin alloy, the phosphorus combines with the copper, the tin being reduced to the metallic state, and on cooling, the copper phosphide separates out in a pure or nearly pure form, and gives rise to the gray network observed; while the redder matrix consists of the copper, or copper-tin alloy containing very little, if any phosphorus.

The special characteristics of phosphor-bronze are, (1) its freedom from corrosion by salt water, which is apparently largely due vertical illumination it will be noticed that as the phosphorus constructive material, as compared with an ordinary zinc-free bronze; (3) the small effect which rise of temperature has upon its mechanical properties, which remain practically unimpaired at temperatures at which zinc containing copper alloys exhibit serious drops in

* *Jour. Institute of Metals*, vol. 1, No. 1, 1909.

strength; (4) a spark cannot be readily obtained from it by a blow; and (5) phosphor-bronzes of high phosphorus content possess low friction coefficients for most metals, and are hard enough to resist abrasion well. On account of the above properties, phosphor-bronze is peculiarly suited for boiler fittings and for fittings exposed to sea water, for the construction of machinery for the manufacture of explosives, and for bearings for high-speed machinery.

The secret of the value of phosphor-bronze for bearings is probably chiefly due, not to its high ultimate tensile strength, but to the fact that the high phosphorous bronzes consist of a network of copper phosphide, supported and held together in a matrix of a softer copper-tin alloy. The bearing surface of the journal is actually this skeleton of phosphide, which possesses a low coefficient of friction for most other metals, and while sufficiently hard to resist abrasion, has its somewhat brittle character rectified by the surrounding and supporting matrix of copper-tin alloy.

It is frequently claimed that in a phosphor-bronze it is only necessary for the most minute traces of phosphorus to be present in order that the material shall possess all the best qualities of phosphor-bronze. Although Philip regards this claim as incorrect, yet he freely admits that very little traces of phosphorus in gun-metals are frequently accompanied by remarkably satisfactory mechanical properties. The following table shows the effect of small amounts of phosphorus on such alloys, the addition being less than 0.005% in each sample.

TABLE 31.—*Strength of phosphorized gun-metals*

Copper, %	Tin, %	Zinc, %	Ultimate tensile strength, lb. per sq. in.	Elongation, % in 2 inches	Reduction of area %
86.60	11.80	1.60	43,680	21.0	20.0
86.60	11.40	2.00	44,352	20.0	23.0
86.70	11.70	1.60	44,128	32.0	30.0
86.80	11.40	1.80	42,560	24.0	23.0
86.50	11.80	1.70	45,920	25.0	25.0
87.00	11.50	1.50	42,560	27.0	29.0

It is doubtful whether such high values can be consistently expected in the case of alloys containing over 11% of tin,

and a zinc content ranging from 1.5 to 2.0% ; and it would be interesting to know just how these were obtained. An alloy extensively used in the United States for automobile worm-gears is known as "Stone's English gear bronze," which is a phosphorized alloy containing 11% tin, 87% copper, 2% of 15% phosphor-copper, and no zinc. Usually 0.2% more tin than contained in this formula is added in weighing the charge to ensure that the bronze will contain 11% of tin by analysis.

This bronze is used for gears and worm-wheels where the conditions are severe, especially where quiet running is a desired feature, and it has to be used against highly finished high carbon or alloyed steel. The physical properties of Stone's bronze follow, according to W. M. Corse:*

Physical properties of alloy of 88.7% copper, 11.00% tin, and 0.3% phosphorus

Ultimate strength, lb. per sq. in.	35,000 to 40,000
Yield point, lb. per sq. in.	22,000 to 25,000
Elongation in 2 inches, %	6.0 to 10.0
Reduction of area, %	7.0 to 9.0
Specific gravity at 20° C.	8.5
Brinell hardness number, 500 kg. load for 30 seconds.	75 to 85
Pattern allowance for shrinkage, inch per foot.	0.125
Weight per cubic inch, lb.	0.31
Compressive elastic limit, lb. per sq. in.	16,000
Coefficient of friction.	0.0040
Modulus of elasticity.	12,000,000 to 14,000,000
Resistance to impact, Fremont notched bar test (fractured sec. 7×10 mm.) kg.-meters.	2 to 4
Endurance of alternating impact, Langraf-Turner or Arnold test alternations.	150 to 300
Resistance to shear, McAdam machine, foot-pounds.	300 to 450

Many tests of this alloy have been made, and the elongation as above has been fairly well-established.

Phosphorus as a deoxidizer.—Phosphor-copper is used extensively as a deoxidizer in bronze in which the best results appear to be obtained when the phosphorus content is kept low, as illustrated by the following tests, two test bars for each, made by the author:

* Transactions of the American Institute of Mining and Metallurgical Engineers, vol. LX, 1919, p. 173.

Alloy 88-10-2

	Pounds		
Copper.....	87.90	Ultimate strength, lb.	44,600 to 45,000
Phosphor-copper.	0.10	Yield point, lb.	23,600 to 21,800
Tin.....	10.00	Elongation in 2 inches, %.	23.0 to 23.0
Zinc.....	2.20	Reduction of area, %.....	22.9 to 22.0

Alloy 88-10-2

	Pounds		
Copper.....	87.90	Ultimate strength, lb.	42,200 to 41,100
Phosphor-copper.	0.10	Yield point, lb.	24,500 to 28,600
Tin.....	10.00	Elongation in 2 inches, %.	17.5 to 17.5
Lead.....	2.00	Reduction of area, %.....	16.1 to 19.7

Alloy 90-10

	Pounds		
Copper.....	89.90	Ultimate strength, lb.	50,000 to 48,600
Phosphor-copper.	0.10	Yield point, lb.	22,600 to 23,800
Tin.....	10.00	Elongation in 2 inches, %.	30.5 to 34.0
		Reduction of area, %.....	34.2 to 30.6

The above test bars were cast in sand molds, cast-to-size, and fin-gated to a riser to feed the bars.

Alloy red brass, fin-risered

	Pounds		
Copper.....	89	Ultimate strength, lb.	35,100 to 36,000
Tin.....	5	Yield point, lb.	16,800 to 17,600
Lead.....	3	Elongation in 2 inches, %.	30.5 to 33.0
Zinc.....	2.12	Reduction of area, %.....	28.1 to 28.3
Phosphor-copper.	0.10		

The following table gives formulas of phosphor-bronze from various sources:

TABLE 32.—Formulas for phosphor-bronze

No.	Description	Copper, %	Tin, %	Zinc, %	Lead, %	Amount of 15% phosphor- copper, %	Amount of 5% phosphor- tin, %
1	Phosphor-bronze, noted for strength and toughness....	90.00	5.00	None	None	None	5.00
2	Elephant bronze, noted for strength.....	85.00	10.50	2.75	1.50	0.25	None
3	Hard, for bearings (4A.)....	73.50	12.00	None	7.50	7.00	"
4	Hard, for bearings.....	79.00	10.00	"	10.00	1.00	"
5	Worm gearing.....	86.00	11.00	"	None	3.00	"
6	Elephant "S" brand.....	76.75	10.25	"	9.00	4.00	"
7	High tensile strength.....	93.00	None	"	None	None	7.00
8	Steam and water pressures....	84.50	12.50	"	"	3.00	None
9	Hydraulic castings (French)..	80.00	11.00	6.00	"	3.00	"
10	Bearings, high pressure.....	82.50	8.00	None	6.00	3.50	"
11	Bearings, heavy pressure roll.	80.00	11.00	"	6.00	3.00	"
12	Bearings and bushings, small.	81.00	5.00	"	12.00	2.00	"
13	Locomotive driving, brasses..	74.00	10.00	"	9.00	7.00	"
14	"Tinless" phosphor-bronze...	77.36	{ 7.51 anti- mony	0.10	12.43	2.00	"
15	Mine pump-valves.....	83.33		None	5.00	None	6.67
16	Plungers.....	88.25	3.50	"	2.50	"	5.75
17	Worm gears, shows no hard spots.....	88.00	11.00	0.50	None	0.50	None
18	Bearing alloy (hard).....	76.50	10.00	None	8.00	5.50	"
19	High-tensile phosphor-bronze.	90.00	5.00	"	None	6.00	"
20	Torpedo gas engine cylinders pressure.....	87.00	None	"	"	None	13.00
21	Pump cylinder.....	84.00	11.00	2.00	2.00	"	1.00

Making phosphor-copper.—The modern method of making phosphor-bronze is by the addition of rich alloys of copper and phosphorus, or tin and phosphorus. These rich alloys are rarely made by the founder using them as they can be bought at a nominal price from numerous sources, some being imported. A number of different methods of making these rich alloys are practiced, one common way is to melt the copper in large crucibles in a pit furnace, having covers split into two pieces, and so equipped as to be easy of manipulation. When the copper is melted under its layer of charcoal, the phosphorizing is carried out by four trained men. Two men—one on either side—manipulate the cover sections, sliding them back and forth quickly as the exigencies of the situation may demand, the third man stands ready with the cakes of phosphorus, which have been weighed and allowance made for loss; and the fourth man stands ready with a heated phosphorizer. All being ready, the two side men pull off the cover sections, exposing the crucible with its molten copper, the third man takes a cake of phosphorus out of his water-pail and tosses it onto the copper, and then the fourth man dexterously spears it with the phosphorizer and forces it into the copper and holds it there until reaction ceases. As quickly as this man spears the fiercely-flaming cake, the two cover men push their sections together. A half-circle cut out of each section of the cover, allows the cover to close and embrace the iron phosphorizer stem. As quickly as the reaction ceases the operation is repeated, and is continued until all the phosphorus has been added. The men who handle the phosphorus and hold it under the copper are the most important aids to the process. All operations must proceed in sequence with rapidity, and the covers must be pushed together after the phosphorus cake has been tossed in, so quickly that the phosphorizer scarcely gets submerged. Stick phosphorus is never used in this operation; it has to be in cakes, because short lengths of stick could not be speared and submerged. Other methods of making phosphor-copper are also in use: Thus at one time copper shavings and turnings

were heated to redness in a tube, and vaporized phosphorus was passed through, converting the turnings into copper phosphide, which was subsequently melted with copper to bring it to an analysis of 15% phosphorus.

Graphite phosphorizers, as shown on figure 60, are used for the introduction of phosphorus into bronze, copper, tin, etc.

Phosphorous vapor can also be passed into liquid copper; also phosphorus can be embedded in shot copper and turnings packed in a crucible, and if properly insulated by a covering of inert material, it will not burn until the copper has reached

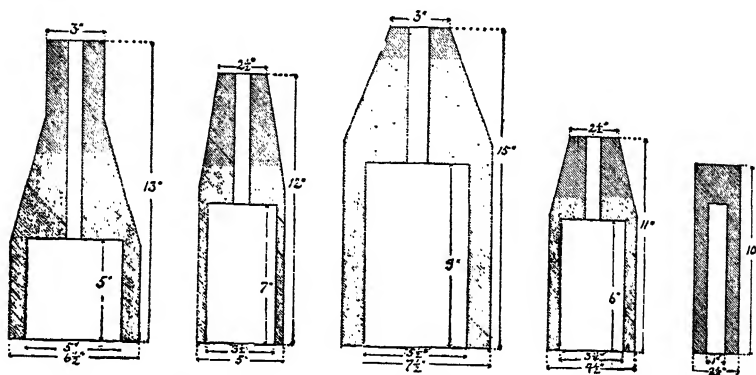


Figure 60.—Graphite phosphorizers (Bartley).

a dull red, when it combines therewith forming a phosphide with the enveloping copper; which, as the heat increases to the melting point, combines with the remainder of the copper, and forms phosphor-copper. The loss of phosphorus in this case will depend upon its insulation.

Phosphor-tin is easily made. The tin should first be granulated or feathered by carefully pouring it into water when the tin is just liquid, but carries little superheat. The granulated tin is weighed with the intention of making a 95% tin-5% phosphorous alloy, and the required amount of phosphorus is packed in the bottom of a crucible or ladle of sufficient size, with the feathered tin on top mixed with small ingots of tin. The vessel is heated, and the phosphorus and

tin combine in a fluid mass, which is then ingoted. It is not necessary to enclose the tin in an iron bomb or container as is sometimes done, because when the container is heated, the phosphorus may burn through. Another method practiced in making both phosphor-tin and phosphor-copper is to have ready a dry loam-lined iron ladle, in the bottom of which is some fine charcoal. The copper or tin is melted in a separate vessel, and when removed from the furnace, the weighed phosphorus is removed from its water-bath and placed on the charcoal, and covered with additional charcoal; then a previously prepared second ladle is set in the first, so that its bottom reaches about one-third down into the first ladle. This top ladle has a perforated bottom, and the metal—copper or tin—is poured into the top ladle and rains onto the phosphorus through the holes. It is advisable to coat the phosphorus with copper by placing it for a few minutes in a solution of copper sulphate.

In all operations in which elemental phosphorus is used to phosphorize metals, it is advisable to copper coat the phosphorus by simply stirring some crystals of blue vitriol (copper sulphate) into the water. The phosphorus reduces the sulphate to copper, which is deposited as a coating on the phosphorus. It is possible to dry the copper-coated phosphorus by gently rolling it on blotting paper, and it can be handled with much greater freedom from danger; but as the coating will peel if too thick, the phosphorus must always be carefully examined to determine if this has not occurred before treating it in any manner that would not be safe in the case of the non-coated phosphorus. Thus it is not wise to carry pieces of copper-plated phosphorus in the vest pocket; a foolish proceeding the author has seen. While this coating of copper is a great safeguard provided it is unbroken, it is never safe to omit all precautions when handling this dangerous chemical.

Properties of phosphor-bronze.—The properties of correctly prepared phosphor-bronze are as follows: Its melting point is nearly the same as that of ordinary bronze. In cooling it shows, however, the phenomenon of passing directly

from the liquid into the solid state without first becoming thickly fluid. In a molten state it retains a perfectly bright surface, while that of ordinary bronze is always covered with a thin film of oxide.

If phosphor-bronze be subjected to continued melting no loss of tin takes place, but the phosphorus content decreases slightly.

The chief properties of phosphor-bronze are its extraordinary toughness and strength. In a cold state it can be rolled, stretched, and hammered. Some properties of drawn metal (phosphor-bronze) are as under:

Tensile strength		Twists in 5 inches		Elongation, %
Wire as drawn, lb. per sq. in.	Annealed, lb. per sq. in.	Wire as drawn	Annealed	
102,759	49,350	6.7	89	37.5
120,957	47,787	22.3	52	34.1
120,950	53,381	13.0	124	42.4
139,141	54,111	17.3	53	44.9
159,515	58,853	13.3	66	46.6
151,119	64,569	15.8	60	42.8

As a bearing metal, phosphor-bronze is useful for a large number of purposes, such as pump cylinders, hydraulic presses, piston rods and rings, eccentric rings, propeller blades, bells, wire, screws, gunpowder machinery, tools, and so forth. Blast-furnaces are sometimes provided with phosphor-bronze tuyères, which are said to give most satisfactory results.

The phosphorus content varies according to the purpose for which the bronze is to be used, an alloy with 8 to 9% tin containing, as a rule, not over, say, 0.4%.

On account of its toughness, density, elasticity, and strength, phosphor-bronze may in many cases serve as a substitute for wrought iron and steel, especially in the construction of articles of complicated form, which require much labor, as well as in the manufacture of wire; non-rusting mine ropes and telegraph wire, for instance. It is also suitable

for ship sheathing, for torpedoes instead of welded steel, cartridge shells, and such like.

Below are given analyses of different kinds of phosphor-bronzes:

Analyses of various phosphor-bronzes

Copper.....	90.34	90.86	94.71
Tin.....	8.90	8.56	4.39
Phosphorus.....	0.76	0.196	0.053

	A	B	C	D	E	F	G	H
Copper.....	85.55	.....	.....	77.85	72.50	73.50	74.50	83.50
Tin.....	9.85	4 to 15	4 to 15	11.00	8.00	6.00	11.00	8.00
Zinc.....	3.77	.....	8 to 20	7.65	17.00	19.00	11.00	3.00
Lead.....	0.62	4 to 15	4 to 15					
Iron.....	Trace							
Phosphorus.	0.05	0.5 to 3	0.25 to 2					

A is used for axle bearings; B and C for softer and harder axle bearings; D to H for railroad purposes, namely, D for distributing slide-valves for locomotives, E and F for axle bearings for cars, G for connecting rods; and H for piston-rods for hydraulic presses. The alloys D to H are richer in zinc than ordinary bronze, and hence are more homogeneous.

SILICON BRONZE

Copper and silicon, with or without tin, may be alloyed to form silicon bronze.

Silicon acts on copper in almost exactly the same manner that phosphorus does, except that it appears to be a more natural alloy, and a flux or reducing agent to the cuprous oxide which is produced when copper is in a melted condition; and it is thereby more active in clarifying, refining, hardening, and strengthening copper and its alloys. In this respect it is more vigorous and pronounced than phosphorus.

Silicon-bronze wire.—Silicon bronze possesses great strength and tenacity, high electric conductivity, and resistance to corrosion. It is well adapted for telegraph and telephone wires. Early specimens of silicon-bronze wire for telegraph purposes had a conductivity of 97%, and a tensile strength

of about $28\frac{1}{2}$ tons to the square inch; and that for telephone purposes had a conductivity of 32% and a tensile strength of $47\frac{1}{2}$ tons.

Later on, a new type of telegraph wire was developed, which possessed less conductivity than the former, but had considerably greater tensile strength, which allowed the wire being more tightly stretched so that the poles could be placed at a greater distance apart. This wire has a conductivity of 80%, and a tensile strength from 35 to 37 tons. At the same time the character of the telephone wire was also changed, raising its conductivity to 42%, and its tensile strength to 52 tons. These wires have been largely used for telephone lines in a number of European cities, and have stood the test of violent storms completely.

The Italian General Telephone Co. has employed silicon-bronze wires with spans as great as 1000 feet. In Vienna, telephone posts are frequently placed at the same distance apart, and carry as many as 78 wires.

Silicon-bronze telegraph wire (A) and silicon-bronze telephone wire (B) of Weiller's patent silicon-bronze contain, according to Hampe:

Analyses of silicon-bronze wires

	A per cent	B per cent
Copper.....	99.94	97.12
Tin.....	0.03	1.14
Iron.....	Trace	Trace
Zinc.....	.....	1.62
Silicon.....	0.02	0.05

The following compositions of silicon-bronze may be recommended:

Analyses of good silicon-bronze

	I per cent	II per cent
Copper.....	97.12	97.37
Tin.....	1.14	1.32
Zinc.....	1.10	1.27
Silicon.....	0.05	0.07

The strength of the above alloys is 600 lb. per 0.001 square inch, extension, 46%, and contraction, 86%. Cast

pins, 3 inches thick, could be readily reduced by rolling to one inch thick.

E. Van der Ven * carefully investigated wires of phosphor-bronze and silicon-bronze, these wires contained, according to chemical analysis by M. Van Eyndhoven, in the case of the phosphor-bronze: Copper, 95.5%; and phosphorus, 2.6%; with small quantities of tin, manganese, and silicon; and in the silicon-bronze, copper, 92.2%; and silicon, 0.91%; with small quantities of tin, manganese, and antimony.

The practical results of Van der Ven's researches are that phosphor-bronze has about 30% of the conducting power of copper, silicon-bronze about 70%, while steel as used in wires has only about 10.5%. Comparing their tenacity—as also very carefully determined by him—with that of steel, he found that a wire of the latter of 2 millimeters diameter, with quadruple security, and the conventional sag of 0.7 millimeter, can have a stretch from pole to pole of 130 meters; while the stretch, under the same conditions of a wire 1 millimeter in diameter, would be 106 meters for phosphor-bronze and 91 meters for silicon-bronze. These alloys, with a diameter of 1.18 and 0.77 millimeters, respectively, have the same electrical resistance as the steel wire of 2 millimeters resistance. The relatively short stretch, which in general increases the expense of construction and maintenance, is less costly in cities, where at short distances the roofs of buildings offer points of suspension for telephone wires. It is thus self-evident that the bronze wires are preferable to those of steel, whose resistance demands a much larger section; the more, since the network of lines suspended in the air cannot be counted among the ornaments of a large city, and are steadily being put in underground conduits. To this result may be added the statements made by M. Bede, at the Paris Electrical Congress, concerning the practicability of the use of phosphor-bronze wire. A phosphor-bronze wire of 0.8 millimeter (costing, too, the same as steel of 0.2 mm.) would, on account of its high elasticity,

* Musée Teyler, and *Electrotech. Zeitsch.*, 1883.

coil up before it has fallen 4 meters from its original position, so rapidly that on breaking it would ordinarily not strike the ground, and hence would be less dangerous. On account of non-oxidation there is no loss of diameter.

Standard silicon-bronze.—The standard silicon-bronze mixture for wire is, according to Sperry, copper, 98.55%; tin, 1.40%; and silicon, 0.05%. When well made it will have the following properties:

Properties of standard silicon-bronze

	Annealed	Hard drawn
Electrical conductivity (Matthiesen's standard), %.....	41	40
Tensile strength, lb. per sq. in. 0.080 wire.....	43,000	92,800
Elongation in 8 inches, %.....	34	1
Reduction of area, %.....	85	68
Twists in 6 inches.....	119	8

The furnace charge for making the above silicon wire is given by Sperry as follows: copper, 98.10%, or 98 lb. 2 oz.; tin, 1.40%, or 1 lb. 6 oz.; and 10% silicon-copper, 0.50%, or 0 lb. 8 oz.

Manganese instead of phosphorus.—By the addition of manganese to molten bronze, the same effect may be produced as by a limited quantity of phosphorus, the dissolved oxides being decomposed and manganous oxide separated.

In 1840, Gersdorff prepared cupro-manganese with 1 part of manganese and 4 parts of copper, and shortly afterwards Schrötter prepared it with 10 to 19% manganese by reducing a mixture of copper scales, pyrolusite, and coal. In 1876, Parsons obtained ferriferous cupro-manganese by melting ferro-manganese in a crucible and adding copper; and, in 1878, Biermann produced cupro-manganese free from iron which contained 74.50% copper, 25% manganese, and 0.50% carbon. The manganese in the alloy exerts, in a manner similar to that of phosphorus and silicon, a reducing effect upon the oxides absorbed by melting bronze, etc., manganous oxide being formed and separated; so that with a moderate addition (3 to 6% of the weight of the charge) only small quantities of manganese remain in the alloy, the strength of the latter being thereby increased. For reducing purposes a

quantity of manganese about four times as large as the cheaper phosphorus is required. By a larger addition of manganese, so that more of it remains in the alloy, hardness and strength are increased, but brittleness less rapidly than by phosphorus.

With a smaller quantity of manganese—say, 4%—cupro-manganese has a copper-red color; and with a larger content—10 to 15%—a yellowish-gray color, and with a still larger content—up to 30%—a gray color. According to Weiller, an alloy with 8% manganese can be readily rolled, but with 12 to 15% it becomes very brittle. An alloy of 75% copper and 25% manganese resists corrosion better than copper. According to Pufahl, two varieties of cupro-manganese contained:

Analyses of two brands of cupro-manganese

Copper Per cent	Manganese Per cent	Iron Per cent	Nickel Per cent	Lead Per cent	Silicon Per cent
68.39 56.29	29.24 40.86	1.29 1.50	0.19 0.10	0.06 Trace	0.07 1.08

Cupro-manganese, generally with 10 to 30% of manganese, serves as an addition to copper or metallic alloys to impart to them, by the withdrawal of oxygen, greater density and strength; and, with a larger manganese content, greater hardness. If, in the oxidation of the manganese, tri-manganic tetroxide is formed, 1 part of oxygen requires 2.585 parts of manganese, but only 0.646 part of phosphorus.

The statements regarding the properties of copper-tin manganese bronze vary considerably, and it is interesting to find in this connection that, about the year 1868, Montefiore-Levi and Künzel made a number of experiments with copper and manganese alloys, and from their results concluded such alloys to be useless. They obtained great tensile strength and toughness with some of the compositions, but their ready oxidation at high temperatures made the qualities of the castings uncertain and impracticable.

Later experiments, however, were more favorable. According to Biermann, the most suitable addition to bronze is 0.66% manganese, which equals 2.66% cupro-manganese with 25% of manganese; in many cases an addition of 0.5 to 2% of cupro-manganese suffices, the alloys then containing only a few hundredths of one per cent of manganese. While good qualities of ordinary bronze broke under a pressure of 39.6 lb. per square millimeter, bronze with 0.66% manganese stood a pressure of 62.15 lb. with an elongation of 20.5%. On account of its great homogeneity, such manganese bronze possesses great resisting power against wear by friction; bearings of bronze with 0.5 to 0.66% manganese being much more durable than other bearing metals without manganese. An alloy of 80% copper, 7 to 9% cupro-manganese, 6% tin, and 5% zinc has proved especially suitable for bearing metal.

Art bronzes.—This term is applied to bronzes which serve for objects of art, such as statuary, vases, and various ornaments. Such bronze should be capable of being cast, and readily worked with chasing tools and gravers. It should resist the influence of the weather, and at the same time, by reason of its hardness, resist mechanical wear. It should have a beautiful color which, to be sure, soon changes under atmospheric influences—that is, becomes darker and partly passes into green; but notwithstanding this change is pleasing to the eye, and never acquires an unsightly appearance like, for instance, that of rusted iron or oxidized zinc.

Bronze may be advantageously used for casting statues, and many antique statues are composed of this material. But in modern times a mixture of metals is used, which, besides copper and tin—the constituents of actual bronze—contains a quantity of zinc, the alloy thus formed being actually an intermediary between genuine bronze and brass. The reason for the use of such mixtures is partly on account of their cheapness—as compared with genuine bronze—and partly in the purpose for which the metal is to be used. A statuary bronze which thoroughly answers the purpose must become thinly-fluid in fusing, fill out the molds sharply, allow of being

readily worked with the file, and acquire a beautiful green color—the patina—on exposure to the air for a short time.

Statuary alloys.—But bronze, even if highly heated, does not become sufficiently fluid to fill the molds completely, and has the further disadvantage of yielding homogeneous castings with difficulty. Brass alone is also too thickly-fluid, and lacks the requisite hardness to allow the fine mending of those parts which have been left imperfect in casting.

Alloys containing zinc and tin, besides copper, can however, be so prepared that they become very thinly-fluid and yield fine castings which can be readily worked with the file and chisel. The most suitable proportions seem to be a zinc content of 10 to 18% and 2 to 4% of tin. In regard to hardness, statuary bronze is a mean between genuine bronze and brass, it being harder and tougher than the latter, but surpassed in these properties by the former.

Being chiefly used for artistic purposes, the color of statuary bronze is of great importance. By small variations in the tin and zinc content, which must, however, be always kept between the indicated limits, the color may be shaded from orange-yellow to pale yellow. With an excessive amount of tin the alloy becomes brittle and difficult to chisel, and by increasing the proportion of zinc the warm tone of color is lost, and the bronze does not acquire, on exposure to the air, a fine patina.

Patina.—This pale-green patina, the beautiful development of which is especially noticeable on ancient—particularly Greek-bronzes, consists essentially of oxides and basic carbonates of the constituents of the bronze, and is formed in the course of time by the chemical action of moisture, and the oxygen and carbon dioxide (CO_2) of the air. The beautiful patina should possess a lustrous tone of color and a smooth surface. Articles coated with it should even, after centuries, preserve their contours in all their fineness and sharpness as produced by casting and subsequent working, as well as their metallic luster.

Such a patina may be noticed on copper which has been

used for roofing and for chased work as, for instance, the Victory group on the Brandenburg gate at Berlin; as well as on numerous bronzes with and without the addition of zinc and lead. On the other hand, copper-zinc alloys without tin, usually turn black when exposed to the air, especially when the zinc content is high (brass), and become coated with a rough, dull layer of oxide, the formation of which very soon impairs the sharpness of the contours. Many bronzes show a similar behavior. Hence, it is evident that the composition of bronze figures erected in the open air exerts an influence on the permanency of their beauty, and many investigations have been made to answer the question of what is the most suitable composition of bronzes for the formation of a beautiful patina. It has been found—at least, generally speaking—that bronzes rich in zinc and poor in tin are in this respect inferior to those poorer in zinc; and that incidental admixtures are also not without influence upon the formation of patina, arsenic especially contributing towards the bronze turning black. A small amount of lead, such as is generally found in European bronzes, does not seem to have an injurious effect. Moreover, the situation of the bronze figure exerts an influence upon the formation of the patina. In a smoky atmosphere, or in one containing sulphuretted hydrogen, even the best bronzes acquire a black instead of a green coating, which consists partly of cupric sulphide and partly of mechanically deposited soot.* On the other hand, even bronzes rich in zinc acquire a green patina if placed in pure air and exposed to atmospheric influences. Finally, it cannot be doubted that the processes of molding and casting are not without influence upon the subsequent formation of patina. Porous castings with rough surfaces will more readily

* In the black coating of the monument of the Elector at Berlin, which was formerly covered with a beautiful patina but has now turned black, Weber found 5.79% of sulphur and particles of soot. In the black coating of two Nuremberg statues, Kämmerer found 4.1 to 6.8% of sulphur and large quantities of sand and soot.

A number of large bronze figures outside of the Carnegie Institute at Pittsburgh, Pa., where the atmosphere is more or less smoky—at times, extremely so—and somewhat charged with sulphurous gases, have little green patina, and are mostly black or brownish.

accumulate dust and soot, and be less inclined to the formations of a beautiful patina than dense castings with smooth surfaces.

Though the alloys best adapted for statues are definitely known at the present time, it happens sometimes that many large castings do not exhibit the right qualities. Their color is either defective, or they do not acquire a beautiful patina, or are difficult to chisel. These evils may be due either to the use of impure metals or to the treatment of the alloy in melting. On account of the large zinc content, there is a considerable loss in melting, amounting even with the most careful work, to at least 3%, and sometimes reaching 10%, and it is evident that in consequence of this loss the alloy will show an entirely different composition from what it should have according to the quantity of metal used in its preparation.

The color of the alloys, as mentioned above, quickly changes by variations in their compositions. The following table gives a series of alloys of different colors suitable for statuary bronze:

TABLE 33.—*Composition and color of statuary bronzes*

Copper per cent	Zinc per cent	Tin per cent	Color
84.42	11.28	4.30	Red-yellow
84.00	11.00	5.00	Orange-red
83.05	13.03	3.92	"
83.00	12.00	5.00	"
81.05	15.32	3.63	Orange-yellow
81.00	15.00	4.00	"
78.09	18.47	3.44	"
73.58	23.27	3.15	"
73.00	23.00	4.00	Pale orange
70.36	26.88	2.76	Pale yellow
70.00	27.00	3.00	"
65.95	31.56	2.49	"

According to d'Arcet, the best bronze for statues consists of 78.5 parts of copper; 17.2 parts of zinc; 2.9 parts of tin; and 1.4 parts of lead; or, 164 parts of copper; 36 parts of zinc; 6 parts of tin; and 3 parts of lead.

In the following table will be found the composition of a few celebrated statues:

TABLE 34.—*Composition of certain statues*

	Copper %	Zinc %	Tin %	Lead %	Iron %	Nickel %	Anti- mony %
Equestrian statue of Louis XIV, cast 1699, by Keller.....	91.40	5.35	1.70	1.37			
Statue of Henry IV, Paris.....	89.62	4.20	5.70	0.48			
Equestrian statue of Louis XV.....	82.45	10.30	4.10	3.15			
Minerva statue, Paris.....	83	14	2	1			
Statue of Napoleon, Paris.....	75	20	2	2			
Old Vendôme column, Paris, from captured cannon.....	89.2	0.5	10.2	0.1			
Alloys of Stiglmayr, Munich, for instance, statue of Bavaria.....	91.5	5.5	1.7	1.3			
Statue of Lessing, Brunswick.....	84.2	11.5	3.55	0.75			
Statues of Melanchthon, Witten- berg, and of Frederick William IV, Cologne, by Gladenbeck.....	89.55	7.46	2.99				
Statue of Count Brandenburg, of Thaer, and of the lion fighter in front of the Museum, Berlin, by Gladenbeck.....	88.88	9.72	1.40				
Statue of Blücher, Berlin.....	90.1	5.3	4.6				
Statue of Frederick the Great, Berlin.....	88.3	9.5	1.4	0.7			
Shepherd, Potsdam Palace.....	88.66	1.28	9.20	0.77			
Bacchus, ".....	89.54	1.63	7.50	1.21	0.18		
Germanicus, Potsdam.....	89.78	2.35	6.16	1.33	....	0.27	
Statue of the Great Elector, Berlin erected 1703.....	89.09	1.64	5.82	2.62	0.13	0.11	0.60
Statue of Frederick William, Berlin. Horse-tamer, Berlin.....	87.44	8.89	3.20	0.65			
Statue of the Elector John William, Düsseldorf.....	84.55	15.63	0.14	0.16			
Statue of Albrecht Dürer, Nürnberg.....	71.74	25.58	2.37	0.91			
	88.6	0.1	5.2	4.5			

Chinese bronzes.—Some bronzes exhibited at the Paris Exhibition attracted special attention, not only on account of their artistic beauty, but also on account of the unusually deep bronze color, which, in many specimens, presented a beautiful dead-black appearance. The color, which was doubtless intended to contrast with the silver of the filigree work, was proved to belong to the substance proper of the bronze, and not to have been artificially produced by any application upon its surface. Analyses of the different specimens of the bronze gave the following results:

Analyses of Chinese bronze

	Per cent		
Tin.....	4.36	5.52	7.27
Copper.....	82.72	72.09	72.32
Lead.....	9.9	20.31	14.59
Iron.....	0.55	1.73	0.28
Zinc.....	1.86	0.67	6.00
Arsenic.....	.....	Trace	Trace

These alloys contain a much larger proportion of lead than is found in ordinary bronze; and it is noticeable that the quantity of lead increases precisely with the intensity of the bronze color, proving, as before stated, that the latter is due to the special composition of the bronze.

Some of the specimens contain a considerable proportion of zinc, but the presence of this metal, instead of improving the appearance, seemed rather to counterbalance the effect of the lead.

In imitation of the Chinese bronze some alloys were made of the following composition:

Analyses of imitation Chinese bronzes

	No. 1	No. 2
	Per cent	Per cent
Tin.....	5.5	5.0
Copper.....	72.5	83.0
Lead.....	20.0	10.0
Iron.....	1.5	
Zinc.....	0.5	2.0

No. 1 produced an alloy exceedingly difficult to work, and, without giving any superior results as regards color, made castings which were extremely brittle.

No. 2, on the contrary, gave an alloy exactly resembling the Chinese bronze. Its fracture and polish were identical, and when heated in a muffle it quickly assumed the peculiar dead-black appearance so greatly admired in the Chinese specimens.

Hitherto it has been found difficult, if not impossible, to obtain this depth of color with bronzes of modern art, since the surface scales off when heated under similar conditions as No. 2.

Japanese bronzes.—Analyses of Japanese bronzes made by M. E. J. Maumene are given on page 358.

All of these alloys show a granulated texture, are blistered in the interior, and are sound on the exterior surface. In the presence of an abundance of antimony their color is sensibly violet, and in the presence of iron, red. The specimens were cast thin, from 0.195 to 0.468 inch, and the mold was well filled.

Analyses of Japanese bronzes

	Per cent	Per cent	Per cent	Per cent
Copper.....	86.38	80.91	88.70	92.07
Tin.....	1.94	7.55	2.58	1.04
Antimony.....	1.61	0.44	0.10	1.04
Lead.....	5.68	5.33	3.54	1.04
Zinc.....	3.36	3.08	3.71	2.65
Iron.....	0.67	1.43	1.07	3.64
Manganese.....	0.67	Trace	1.07	3.64
Silicon.....	0.10	0.16	0.09	0.04
Sulphur.....	0.10	0.31	0.09	0.04
Undetermined.....	0.26	0.79	0.21	0.56

Old Peruvian bronze.—An old chisel, weighing about 7 oz., found at Quito, and which had evidently been used for working trachyte,* showed, according to Boussingault the following composition: 95% copper, 4.5% tin, 0.2% lead, 0.3% iron, and traces of silver.

A chisel brought by Humboldt to Europe from a silver mine worked by the Incas consists of 94% copper and 6% tin. Charlton ascribes the hardness of the tools used by the Peruvians in mining, which consisted of 94% copper and 6% tin, to the presence of a small quantity of silicon.

A Turkish bronze basin examined by Fleck was composed of 78.54% copper, 20.27% tin, 0.54% lead, and 0.19% iron.

An antique bronze weapon in the form of a chisel, which was found near Bremen, was composed of 85.412% copper, 6.846% tin, and 0.346% iron.

*A nearly compact, feldspathic, volcanic rock, breaking with a rough surface, and often containing crystals of glassy feldspar, with sometimes hornblende and mica.

CHAPTER XII

STEAM AND ELECTRIC RAILROAD ALLOYS

STEAM RAILROAD ALLOYS

A large proportion of the castings used on the rolling stock of steam railroads is for bearing purposes. For instance, on the locomotives there are driving brasses, tender brasses, rod brasses, gibs, rod bushings, bells, and steam fittings; on the coaches are bearings for the wheel axles, with some hardware and ornamental parts, although recent years have witnessed a great curtailment in the use of brasswork on coaches; and freight cars are fitted with bearings of brass. The latter and passenger coach bearings consumed the enormous amount of 100,000,000 lb. of brass during 1914, according to G. H. Clamer.* Locomotive bearings, and some car journal bearings, are made of a high-grade bearing alloy. At one time, such parts as driving brasses were made of an alloy of 1 part tin to $5\frac{1}{2}$ to 7 parts copper, but alloys containing considerable lead are frequently used for these fittings now.

An example of the class of phosphorized alloys used for driving and rod brasses, also for other brass subjected to rolling or sliding friction, is the following formula:

Bearing alloy

	Pounds
15% Phosphor-copper.....	8.00
Copper.....	72.16
Lead.....	10.30
Tin.....	9.54

* *The Brass World*, Feb., 1914, p. 43.

The average analysis of this bronze will run as follows:

	Per cent
Copper.....	79.30
Tin.....	10.36
Lead.....	9.34
Phosphorus.....	0.83
	<hr/> 99.83

This metal is frequently melted in furnaces of the type shown in figure 61, which is known as the "Simplex" furnace, made by the Monarch Engineering & Mfg. Co., of Baltimore, Maryland. The capacity of such furnaces ranges from 500

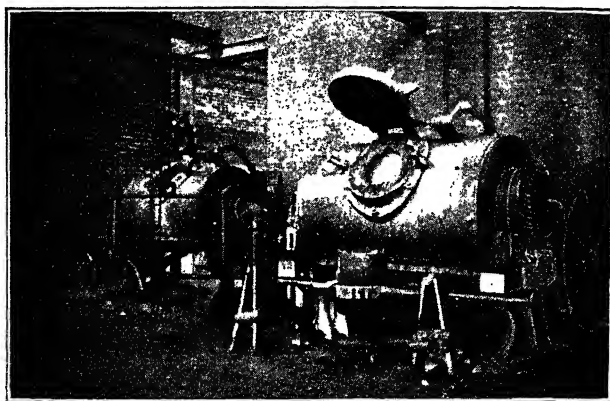


Figure 61.—Simplex melting furnace (Monarch "C," no crucible).

to 24,000 lb. of metal per heat. The metal charged, and the analysis of the bearing alloy, are given as a guide in making the alloy to specifications in this type of furnace.

Pouring temperature.—On account of the large amount of phosphorus this alloy contains it is necessary to pour it into sand molds within a narrow range of temperature. If poured hot, it is so liquid that it will sink into the sand like water, forming very rough castings, sometimes to the point of being impossible to clean. When poured "cold," the castings will either run "cold shut," or are porous when machined. It is necessary to know by experience the proper pouring temperature. It is possible to detect immediately the time to pour; and when this stage is reached no time must be lost in getting

the metal into the molds. If successful, the castings will be smooth of surface, but dark colored; in fact, when poured a trifle too high in temperature, they will be black of skin, and probably cut into the sand a little. When time allows, and in the case of large castings, the best way to make castings of heavily phosphorized bronze is to make the molds by using a facing of new and sharp sand, bonded with dextrin; and after the pattern has been drawn, paint it with good plumbago mixed with sugar syrup (molasses can be used if free of sulphur dioxide). Paint the molds and the gates; set the cores and seal with plumbago; wash all openings around core prints; then bake the molds in the oven. Such molds can be poured with phosphor-bronze without waiting for the exact casting temperature.

Bearing metal used by Pennsylvania Railroad.—The amount of bearing metals consumed by the Pennsylvania Railroad during the year 1917 was placed at 21,380,000 lb. by F. M. Waring, Engineer of Tests, in a paper presented before the American Institute of Mining and Metallurgical Engineers, at its Milwaukee meeting in October, 1918. The composition of the non-ferrous alloys used by that Railroad were given as follows:

TABLE 35.—Composition of alloys used by the Pennsylvania Railroad

Name	Copper, %	Tin, %	Lead, %	Phos- phorus, %	Anti- mony, %	Zinc, %
Phosphor-bronze, Special 32-C.....	79.70	10.00	9.50	0.80	None	None
Extra B-bronze, Special 141.....	76.75 (b)	8.00 (c)	15.00 (d)	0.25 (e)	"	" (f)
Car-journal, bronze (a)...						
Special high-lead bronze, Special 59.....	70.00	5.00	25.00	None	"	None
Lining metal, Special 57..	.....	.....	87.00	"	13.00	"
Dandelion metal.....	.....	10.00	72.00	"	18.00	"
Bell metal.....	83.33	16.67	.....	"	None	
Babbitt, tin base.....	3.70	88.90	.....	"	7.40	
Babbitt for motor bearings.	1.00	50.00	38.50	"	10.50	

(a) Means sum of copper, lead, tin, and zinc, not less than 99.

(b) Not less than 71.

(c) Not less than 4.

(d) Not less than 13.

(e) Not less than 0.20.

(f) Not more than 3.

Phosphor-bronze is used principally for rod bushings; main rod brasses; and crosshead shoes. Extra B bronze is to a small extent used for the backs of car and coach bearings, but the majority of these are now made of the car-journal bronze, which contains, on the average about 5% of tin. Car-journal bronze is used for making car and coach bearing backs at the Altoona brass foundry by melting down old backs after removing the linings, and making the necessary addition of new metal to bring the composition within the limits given in the table.

Special high-lead bronze is used principally for locomotive driving-box shells, which are not lined. Dandelion metal is used for lining crosshead shoes, and for lining engine truck and trailer bearings, as well as for hub liners, in place of phosphor-bronze on freight locomotives.

Bell-metal is used exclusively for making locomotive bells, and during 1917 about 42,800 lb. of these castings were made for this railroad.

Tin-base babbitt is used in the shops, but its use has been curtailed on account of its cost, and the lead-base alloys have been largely substituted with success.

Car-journal bearings.—The subject of alloys used for car-journal bearings on American railways was very thoroughly covered by G. H. Clamer in a paper* presented before the American Institute of Metals in 1915, from which we take the following excerpts:

Bearings as first used contained considerable tin; they belonged to the series of bell-metals, and gave no trouble until heavier equipment and greater speeds became the rule. Then the annoyance of hot boxes became very serious, and led to the introduction of soft metal linings with shells of the same alloys, until competition forced the use of cheaper metals, until a standard of 80% copper; 10% tin, and 10% lead was arrived at. But competition grew stronger and stronger, with the result that scrap metals came into use—at first with

* Transactions American Institute of Metals, vol. IX, 1915, pages 241 to 263.

caution, but later with entire disregard of the value of the metal from a bearing standpoint. Thus, zinc was finally introduced into the bearings, where previously it had been excluded; and in time the following specification was adopted, which, strange to say, was found to be a better bearing metal

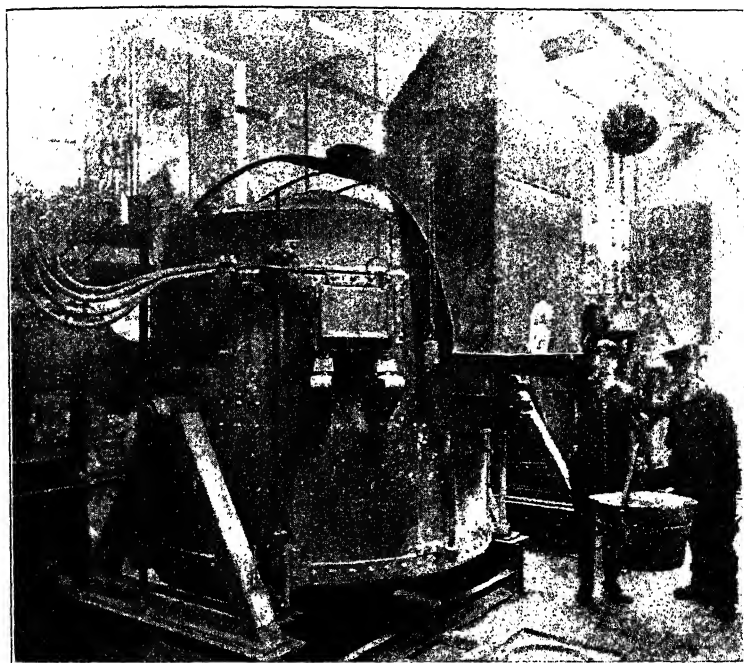


Figure 62.—Baily electric furnace (courtesy Lumen Bearing Co.).

for this special purpose than the so-called standard, or 80-10-10:

Car-journal bearing alloy

	Pounds
Copper.....	70
Lead.....	20
Tin.....	5
Zinc.....	5

The above alloy, or its modification, is now practically standard for car-journal bearings. Some specifications adopted by railroads for this type of bearing are given by Clamer as follows:

TABLE 36.—Specifications for car-journal bearings*

Name of Railroad	Copper, %	Lead, %	Tin, %	Zinc, %	Iron, %	Phosphorus, %	Impurities, %
Atlantic Coast Line.....	73	15	9 (min.)	3 (max.)	.....	.....	Inc. zinc 3 (max.)
Baltimore & Ohio.....	72-80	10-16	7 (min.)	.....	.....	.....	Inc. zinc 0.75 (max.)
Barney & Smith Car Co.....	78-80	10-13	9-11	.....	.....	.....	Inc. zinc 3 (max.)
Bessemer & Lake Erie.....	65-70	15-20	4-5	10-15	.....	.....	No mention
Boston & Maine.....	77-80	10-13	9-11	3 (max.)	.....	.....	Inc. zinc 3 (max.)
Buffalo, Rochester & Pittsburgh.....	77-80	9-11	7-9	.....	.....	.....	.....
Canadian Pacific.....	75-80	10-16	9	3 (max.)	0.25	.....	Inc. zinc 3 (max.)
.....	75	15 (max.)	7 (min.)	3 (max.)	0.25	.....	.....
.....	70	20 (max.)	7 (min.)	.....	.....	.....	.....
Central Railroad of New Jersey.....	77	15	8	.....	.....	0.02	Arsenic, 0.02 (max.)
Chicago & Alton.....	75-80	10-14	7-10	.....	.....	0.7	Inc. zinc 1 (max.)
Chicago, Burlington & Quincy.....	77-81	9-11	9-11	0.5	.....	.....	0.75 (max.)
Chicago & Eastern Illinois.....	75	10-15	6	.....	.....	.....	No mention
Chicago, Milwaukee & St. Paul.....	80	10-15	10	.....	0.5	.....	Inc. zinc 3 (max.)
Chicago Railways.....	75	19 (max.)	6 (min.)	.....	.....	0.7	Inc. zinc 0.5
Edgell, Joliet & Eastern.....	78-80	10-13	9-11	.....	0.25	.....	.....
Grand Trunk.....	72	15-20	7	.....	.....	.....	.....
Great Northern.....	72-80	10-16	9	.....	.....	.....	.....
Island Canal.....	75	10-15	6	5	.....	.....	.....
Kansas City Southern.....	75-80	7-11	10-15	.....	.....	.....	Inc. zinc 3 (max.)
Lehigh Valley.....	68	25 (max.)	4-5	2 (max.)	.....	.....	0.75 (max.)
Michigan Pacific.....	75-80	10-18	7-11	.....	.....	.....	Inc. zinc 3 (max.)
New York Municipal.....	77	15	8	.....	.....	.....	Inc. zinc 3 (max.)
Northern Pacific.....	72-80	10-16	9	.....	.....	.....	0.5 (max.)
Philadelphia & Reading.....	77	15	8	.....	.....	.....	Inc. zinc 3 (max.)
Pressed Steel Car Co.....	64-70	26-32	4-6.5	.....	.....	0.2	Inc. zinc 3 (max.)
Rock Island.....	75-80	10-15	6-10	5 (max.)	.....	.....	I (max.)
St. Louis & San Francisco.....	75	10-15	6	5 (max.)	.....	.....	Inc. zinc 3 (max.)
Seaboard Air Line.....	75-80	10-18	7-11	.....	.....	.....	No mention
Southern.....	65-75	Remainder	4-10	.....	.....	.....	Inc. zinc 0.75 (max.)
Southern Pacific.....	75-78	10-16	6-8	.....	.....	.....	Inc. zinc 3 (max.)
Spokane, Portland & Seattle.....	72-80	10-16	9	.....	.....	0.02	Inc. zinc 3 (max.)
Union Tank Line.....	78	16	6	2	.....	.....	Trace
Virginian.....	68	26.5	5.5	.....	.....	.....	I (max.)
Wabash.....	75	10-16	6	3 (max.)	.....	.....	Inc. zinc 1 (max.)
Western Pacific.....	72-80	10-16	9-14	.....	.....	.....	.....

* G. H. Clamer in Transactions American Institute Metals, 1916, Vol. IX, pp. 245-246

At one time, car-journal bearings were made of the lowest grade of scrap metals which could be gathered together. The source of the copper used was "copper bottoms"—that is, the bottoms of wash-boilers and other household utensils. These were pounded into shape to fit the crucibles, no attempt being made to remove the iron wire that formed the bead at the upper edge of the all-copper boilers. This would be fished out when the metal was molten, and naturally a large amount

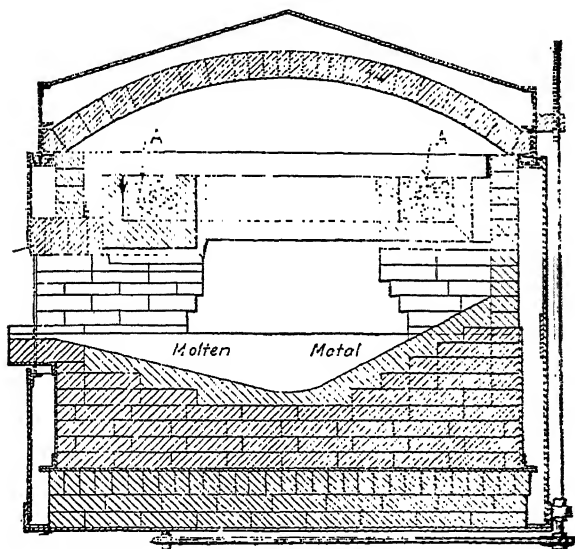


Figure 63.—Section of Bailey electric furnace.

of iron was included in the brass. When the brasses were poured "bearing up," this iron caused no difficulty because the metal in the mold was at a lower level than the pouring gates and sprue. In the days of hand molding, up to $4\frac{1}{4}$ by 8-inch brasses were made 3 in a mold; and both shells and solids were made without risers anywhere, simply a flat gate which dipped down into the bearings at the middle of one end. Considering the metal, and the method of molding and gating, it is surprising how good these castings were. The material, aside from the copper bottoms, consisted of light brass scrap, which in some foundries as a preliminary was

melted in large quantities and run into big ingots, which were re-melted with copper, lead, and zinc.

On machines, these bearings were made two in a mold, one machine made drags, another made copes. All car brasses are babbitted, those called "shells" being hollowed out to reduce the brass and increase the cheap babbitt, which in many cases was simply antimonial lead (80% lead, and 20% antimony). The solid bearings had to be bored out in specially designed boring mills with a large production capacity. After boring, the ends were chamfered, and the bearings went to the tinning kettle, previous to which they were swabbed with soldering fluid. The "tin" would only coat where the acid had been put, that is, the bearing surface. The babbitting was done by clamping the bearing against a water-cooled mandril, and then filling up the space between the bearing surface and the mandril with babbitt using a small ladle; this work was carried out expeditiously. After babbitting, the ends of the bearings had to be trimmed off, which was done in a machine with special cutters, then the brasses were ready to ship.

Outside of the car-journal brasses, which, as shown by the specifications of the various railroads are expected to be made of a good grade of alloys, there are large quantities of bronze castings used on the locomotives, which, as before remarked are made of a high-grade metal. Some brass foundries devote their time almost exclusively to steam railroad brasses, and being equipped for this class of castings have a decided advantage over the ordinary brass founder. Thus the Eureka Brass Co. of St. Louis, Missouri, has a daily capacity of 100,000 lb. of castings of this type, which comprise locomotive bearings, car-journal bearings, babbitt metals, and all the other alloys ordinarily used by steam roads.

ELECTRIC RAILROAD ALLOYS

Electric railroads use a considerable amount of brass work, probably more in proportion than the steam railroads. The same type of bearings are used to carry the weight of the cars on the axles as in the case of the steam roads, but there

are also the bearings of the motors, the copper and brass parts used in the controlling apparatus, the overhead equipment, and the trolleys. In addition to this, the power-houses require a considerable amount for stationary steam engines, when steam is used, and for the switchboards and transmission-lines.

Splicers and trolley ears.—The overhead equipment uses trolley ears and splicers, and crossovers and switches. Trolley ears are the castings which hold up the trolley wire; they consist of a boss with a tapped hole to attach the ear to the span wire, this boss being placed at about the center of a grooved straight body, which is clasped over the trolley wire. Trolley ears have to be ductile and strong, and experience has shown that a red brass meets these requirements best. A representative trolley ear mixture will be as follows:

<i>Trolley ear mixture</i>		Pounds
Copper.....		87.00
Zinc.....		8.00
Tin.....		3.00
Lead.....		2.00

Splicers are used to join broken stretches of wire, also to connect two lengths of wire. They should be a little harder than the trolley ear, about as follows:

<i>Mixture for splicers</i>		Pounds
Copper.....		86.50
Zinc.....		6.50
Tin.....		4.50
Lead.....		2.50

As a crossover and a switch get a lot of pounding from the trolley wheel, they should be a little harder than the splicers, as follows:

<i>Mixture for crossovers</i>		Pounds
Copper.....		90.00
Tin.....		6.50
Zinc.....		2.00
Lead.....		1.50

Where the service is very severe, a little harder mixture than the above may be used to advantage, and the tin may be increased to 8%, with a corresponding decrease in copper.

The tendency, in this case, as in all others, is to use as cheap material as possible, consequently mixtures inferior to those given are frequently used. This should not be permitted, as the mixtures given are as cheap as consistent with a proper fulfillment of the requirements of the case.

Trolley wheels.—Another class of castings used on electric railroads are trolley wheels. On some high-speed lines the tendency is to dispense with the trolley wheel, and use a sliding contact or shoe, or a long roller working in a frame of pantograph shape and action. Some high-speed suburban roads simply cut a trolley wheel in half, and batter the harp to hold the wheel section firmly, so the thread will contact with the wire and let it slide, which seems to give good service. Street railways use trolley wheels, and the standard mixture may be said to be as follows:

<i>Trolley wheel mixture</i>		Pounds
Copper.....		92.00
Tin.....		6.00
Zinc.....		2.00

There are variations of this mixture; sometimes the zinc is omitted entirely, and about 1% of 15% phosphor-copper is substituted. In other cases the wheels are simply hardened with phosphorus. Some so-called authorities contend that the wheels should contain no zinc—also no lead—as zinc favors arcing. Against this is the fact that alloys containing 38% of zinc have been used with good service. Theoretically, the best trolley wheel should have a tread of high conductivity copper, with flanges of hard, tough bronze, stiff spokes or web, and an oilless bearing.

Trolley harps.—The harp is the brass part in which the trolley is held, and is connected to the pole. This casting should be made of a ductile alloy of sufficient stiffness to hold its shape, and for this the alloy used for crossovers is suitable.

Axle bearings.—A good mixture for axle bearings is “extra B bronze, special 141,” of the Pennsylvania Railroad, as given under steam railroads. For car-journal bearings, the same formulas as used for steam roads are suitable.

Contact fingers.—For copper contact fingers for controllers, when cast, an alloy of copper and iron should be used as it does not spark. This can be made by melting copper under charcoal, and when just liquid, adding one pound of yellow prussiate of potash. Allow this to boil until all water is driven off, then stir into the metal.

CHAPTER XIII

STEAM METALS AND RED BRASS

ALLOYS that contain copper, tin, lead, and zinc are known as composition metals, steam metals, or red brass. The straight copper-tin alloys are used to a limited extent in modern foundries.

Action of zinc and lead.—The majority of castings made will contain all four metals, for the reason that the addition of zinc and lead modifies the properties of the metals, and makes them more satisfactory for the purposes for which they are used. Thus, zinc is supposed to act as a deoxidizing agent; this it does to a very limited extent, as anyone who has cast such an alloy as the 88-10-2 can testify. As a matter of fact, it requires more than 2% of zinc to make copper run into sand molds without blowholes. In ordinary commercial brass-foundry practice it will require 3% of zinc to make copper run sound. Therefore, instead of 88-10-2 it should be 87-10-3, to take advantage of the deoxidizing power of the zinc and leave a margin of safety.

Lead is added to facilitate machining; also, as the lead is mechanically mixed and not alloyed, it has a tendency to lodge in places where there would be a void, but for its presence; therefore, for metals which must withstand pressure, additions of lead are advisable. Thus, the 88-10-2 alloy is greatly improved by the introduction of the other two metals so common in brass-foundry practice. As the result of a great deal of experimental work, the 88-10-2 formula for some special work was changed to the following alloy, with advantages which will be recognized from the tests given:

Improved 88-10-2 alloy

	Pounds
Copper.....	98.00
Tin.....	9.50
Zinc.....	2.00
Lead.....	0.50

In making the melt, 2 oz. of 15% phosphor-copper was placed in the bottom of the crucible with the cold metal. A few tests taken at random follow:

Tests of an 88.0-9.5-2.0-0.5 alloy

	Heat 40	Heat 41	Heat 42	Heat 43	Heat 44
Yield point, lb.	21,100	20,300	21,500	19,400	21,600
Ultimate strength, lb.	40,000	46,000	50,200	38,100	42,500
Elongation in 2 inches, %..	16.0	40.0	39.0	21.5	22.0
Reduction of area, %.....	19.6	32.9	34.4	21.3	22.4

	Heat 62	Heat 64	Heat 66	Heat 69	Heat 70
Yield point, lb.	18,600	21,500	22,100	13,500	25,500
Ultimate strength, lb.	36,800	44,900	53,100	54,900	50,600
Elongation in 2 inches, %..	24.0	35.5	44.0	57.5	35.0
Reduction of area, %.....					

The variations from heat to heat will serve to prove to the initiated that the tests were not made in the laboratory, but in the foundry, as the heats which were neglected in the furnace can be immediately identified. However, even the poorest tests would pass any ordinary tensile specifications for the 88-10-2 alloy, showing the modification made by cutting the amount of tin and putting lead in its place resulted in a better bronze.

Standard steam metal.—What has been termed by Sperry as the “standard steam metal” mixture follows:

Analysis of standard steam metal

	Per cent
Copper.....	87.00
Tin.....	7.00
Zinc.....	3.00
Lead.....	3.00

In spite of the 3% of zinc in this alloy, it will be found advisable for pressure castings to place $1\frac{1}{2}$ oz. of phosphor-copper in the bottom of the crucible, with the cold copper on top.

Valve metal.—The mixture just given can be relied upon as being a good steam metal. An average analysis of 10 valves from different makers follows:

<i>Average analysis of valve metal</i>	
	Per cent
Copper.....	86.17
Zinc.....	8.58
Tin.....	3.24
Lead.....	1.13

None of these valves was made from good steam metal; the mixture was simply a red brass, in which the zinc content was the highest of the soft metals.

Composition mixtures.—In table 37 are given examples of steam and red brass alloys.

Red brass.—Regarding the mixtures given in the table, the best alloys of copper that can be made for any purpose are those in which tin predominates among the white metals. Whatever the percentage of tin may be, it should not be overshadowed by lead unless a very free cutting, bronze-colored metal is desired, such as in the alloy which is typical of the class known as red brass. This is known as red brass No. 17, and is a very suitable alloy where pressure or shock conditions are not severe. The fracture is homogenous, and the alloy has been extensively used for plumbers' red-metal castings.

<i>Charge for No. 17 red brass</i>	
	Per cent
Copper.....	83.00
Tin.....	2.00
Lead.....	10.00
Zinc.....	5.00

No. 17 red was put together by the author as a result of a number of carefully made tests. The fracture is perfectly homogenous, and the alloy can be recommended for any pur-

TABLE 37.—Composition of steam and red brass alloys

Used for	Copper, %	Tin, %	Lead, %	Zinc, %
Plumbers' brass goods.....	84.00	4.00	4.00	8.00
“ “ “	85.00	5.00	5.00	5.00
Valves and steam fittings.....	87.00	4.25	1.50	7.25
Faucets, analysis.....	87.55	3.60	4.00	4.85
Wagner's valve, Chemnitz, Ger- many, No. 1.....	84.00	4.00	2.00	6.00
Wagner's No. 2 valve.....	94.00	4.00	2.00	
Waste and stopcocks.....	85.00	7.00	3.00	5.00
Transit Development Co., steam fittings.....	88.50	5.50	2.50	3.50
Valves (Globe).....	85.00	4.00	5.00	6.00
Radiator valves.....	84.00	4.00	4.00	4.00
Steam check-valve bonnets.....	72.00	9.00	2.00	17.00
Radiator valves (cheap).....	87.75	3.50	2.00	7.00
“ “ “	77.00	3.00	10.00	10.00
Valve body (cheap).....	84.00	3.50	6.25	6.25
Steam metal.....	88.00	5.00	3.50	3.50
Cheap red (very soft).....	83.00	.....	8.50	8.50
“ “ (soft).....	83.00	1.00	8.00	8.00
Plumbers' red brass.....	83.00	2.00	4.00	11.00
Cheap, half red.....	83.00	1.00	6.00	15.00
Tough yellowish red.....	85.00	2.00	3.00	15.00
Red (good color).....	82.50	1.50	6.00	10.00
Gasoline stove burners.....	80.00	3.00	3.00	15.00
Sprinklers.....	85.00	3.00	2.00	10.00
Valves and fittings (cheap).....	73.00	1.75	6.75	18.50
Water cocks and bibbs.....	82.00	2.00	8.00	8.00
Molds for casting soft metals.....	91.00	6.00	1.00	2.00
Key metal.....	80.00	10.00	5.00	5.00
Screen plates.....	85.00	5.00	8.00	2.00
Plumbers' faucet yellow.....	70.00	.....	3.50	26.50
Hose couplings.....	65.00	2.00	3.00	30.00
Cheap composition.....	85.00	3.00	3.00	9.00
Statuary bronze.....	90.00	6.00	1.00	3.00
Bureaus statuary bronze (1).....	89.50	7.00	0.50	3.00
“ “ “ (2).....	89.50	5.00	0.50	5.00
Ordinary steam metal.....	88.00	5.50	2.50	4.00
Trolley wheels.....	92.00	6.00	.....	2.00
Trolley ears.....	85.00	3.00	3.00	9.00
Pattern castings.....	80.00	8.00	2.00	2.00
Carburettors.....	87.00	7.00	3.00	3.00
Name plates.....	86.00	3.00	2.00	9.00
Hardware bronze.....	85.00	3.00	3.00	9.00
Analytical scale beams.....	79.00	18.00	1.00	2.00
Bullion balance beams.....	84.00	13.00	1.00	2.00
Bolts and nuts.....	90.00	8.00	.....	2.00
Marine hardware.....	88.00	5.00	2.00	5.00

pose where a red brass is suitable. Its physical properties are as follows:

Physical properties of No. 17 red brass

Ultimate tensile strength, lb. per sq. in.....	19,000 to 23,000
Yield point, lb. per sq. in.....	10,000 to 11,000
Elongation in 2 inches, %.....	7.0 to 13.0
Reduction of area, %.....	11.0 to 17.0
Specific gravity, at 20° C.....	9.0
Brinell hardness number, 500 kg. load for 30 seconds.....	34
Patternmaker's allowance for shrinkage, inch per foot.....	0.14
Weight per cubic inch, lb.....	0.33
Compression, elastic limit, lb. per sq. in.....	8,000

No. 17 red has the color of gun-metal. The following red brass is stronger, but the color inclines to a yellow shade:

Charge for No. 18 red brass

	Per cent
Copper.....	83.00
Tin.....	2.00
Zinc.....	11.00
Lead.....	4.00

No. 18 red has been used extensively for making plumbing castings, such as small cocks and faucets. During the years that zinc soared in price it was replaced by No. 17, and No. 18 never recovered its place, owing to the superior color of No. 17.

In referring to red-brass alloys, as there are so many mixtures it is necessary to have some means of identification, therefore the numbers given by one large manufacturer will be retained here. An example of what is probably the cheapest red brass it is possible to make, and still have it classed as such is the following alloy—No. 23:

Charge for No. 23 red brass

	Per cent
Copper.....	79.00
Tin.....	2.00
Zinc.....	12.00
Lead.....	7.00

This brass is still used extensively for making small valves and other castings subjected to ordinary household water pressures. Such castings are tested by water to a pressure of

100 lb. per sq. in.; and No. 23 red will normally have a leakage loss of 4%. Its color is not the rich color of No. 17 red.

Many manufacturers prefer a higher grade of red brass than any of the examples so far given, and the following alloy, No. 19, may be suitable in such cases:

Charge for No. 19 red brass

	Per cent
Copper.....	83.00
Tin.....	4.00
Zinc.....	7.00
Lead.....	6.00

This alloy is well known, although is here given the number 19, for convenience. It may be obtained as a standard ingot, and in such shape a considerable saving can usually be effected. Its physical properties are as under:

Physical properties of No. 19 red brass

Ultimate tensile strength, lb. per sq. in.....	28,000 to 33,000
Yield point, lb. per sq. in.....	14,000 to 16,000
Elongation, % in 2 inches.....	15.0 to 20.0
Reduction of area, %.....	20.0 to 26.0
Specific gravity at 20° C.....	8.5
Brinell hardness number, 500 kg. load for 30 seconds.....	55 to 60
Patternmaker's allowance for shrinkage, inch per foot.....	0.125
Weight per cubic inch, lb.....	0.31
Compression, elastic limit, lb. per sq. in.....	10,000

An example of a better grade of red brass, one suitable for ordinary steam-pressure goods, is alloy No. 20 red, as follows:

Charge for No. 20 red brass

	Per cent
Copper.....	89.00
Tin.....	5.00
Zinc.....	3.00
Lead.....	3.00

Its physical properties are as follows:

Physical properties of No. 20 red brass

Ultimate tensile strength, lb. per sq. in.....	34,000
Yield point, lb. per sq. in.....	16,000
Elongation, % in 2 inches.....	26.0 to 31.0
Reduction of area, %.....	29.0
Specific gravity at 20° C.....	8.9
Brinell hardness number, 500-kg. load for 30 seconds.....	40 to 45
Weight per cubic inch, lb.....	0.32
Patternmaker's allowance for shrinkage, inch per foot.....	0.14
Compression, elastic limit, lb. per sq. in.....	11,500

An example of a still higher grade metal is found in No. 11, as follows:

No. 11 alloy, soft gun-metal

	Per cent
Copper.....	90.00
Tin.....	6.50
Zinc.....	2.00
Lead.....	1.50

Its physical properties are as follows:

Physical properties of No. 11 alloy

Ultimate tensile strength, lb. per sq. in.....	34,000 to 40,000
Yield point, lb. per sq. in.....	18,000 to 22,000
Elongation, % in 2 inches.....	25.0 to 33.0
Reduction of area, %.....	26.0 to 34.0
Specific gravity at 20° C.....	8.8
Brinell hardness number, 500-kg. load for 30 seconds.....	50 to 60
Patternmaker's allowance for shrinkage, inch per foot.....	0.14
Weight per cubic inch, lb.....	0.32
Compression, elastic limit, lb. per sq. in.....	13,000

No. 11 is used extensively in the automobile industry for high-grade small bearings, which are babbitt-lined. It is also suitable for severe service steam work, and for castings subjected to pressure, and for the latter purpose the alloy is modified as follows:

Gun-metal for high pressures

	Per cent
Copper.....	89.00
Tin.....	6.50
Zinc.....	2.00
Lead.....	1.50
Nickel.....	1.00

The nickel must not be added in the form of metallic nickel, otherwise the castings may not be sound. Add the nickel as one-third copper, one-third nickel, one-third tin, making the proper allowances. Such an alloy may be obtained commercially, and it carries the proper amount of deoxidizer, as determined by experience.

The specification of G bronze, U. S. Navy Department, is copper, 87 to 89%; tin, 9 to 11%; zinc 1 to 3%; iron, maxi-

mum 0.10%; and lead, maximum 0.20%. This alloy is practically as follows:

Composition and properties of G bronze

	Per cent
Copper.....	88.00
Tin.....	10.00
Zinc.....	2.00
Ultimate tensile strength, lb. per sq. in.....	32,000 to 38,000
Yield point, lb. per sq. in.....	32,000 to 38,000
Elongation, % in 2 inches.....	14.0 to 18.0
Reduction of area, %.....	12.0 to 15.0
Specific gravity at 20° C.....	8.7
Brinell hardness number, 500 kg. load for 30 seconds.....	70 to 75
Patternmaker's allowance for shrinkage, inch per cubic foot.....	0.125
Weight per cubic inch, lb.....	0.32
Compression, elastic limit, lb. per sq. in.....	15,000

The Navy specifications for composition G are:

Minimum tensile, 30,000 lb.; maximum yield, 15,000 lb.; and minimum elongation, 15 per cent.

The specification of composition H, U. S. Navy Department, are copper, 82 to 84%; tin, 12.5 to 14.5%; zinc, 2.5 to 4.5%; lead, 1.00%; and iron, maximum 0.06%. The normal alloy contains copper, 83%; tin, 13.5%; and zinc, 3.5%. The following composition was used by the author, and the effect of additions of deoxidizers determined by making fracture test bars which were broken to ascertain the effect on the alloy, bearing in mind that any disturbance of the fracture is to be avoided:

Analysis of modified composition

	Per cent
Copper.....	82.75
Tin.....	13.50
Lead.....	0.75
Zinc.....	3.00

The Brinell hardness number was 126, using a 3000-kg. weight. In color and grain the fracture of the alloy untreated with deoxidizer was uniform throughout. It is, however, subject to inclusions of green dross, which is partly eliminated by pouring hot. A little phosphorus is advisable. The fracture test bars were 1.75 by 1.75 by 6 inches, and tests were made with the following additions:

Deoxidizer	Appearance of Fracture
Phosphor-copper (15%) added 0.0375% P	{ Fracture disturbed; mixed, two alloys yellow and gray
Phosphor-copper (15%) added 0.0375% P	
Arsenical tin (2% As) used 1%, added 0.02% As	Fractured surfaces showed two alloys mixed; too much phosphorus
Chromium copper (10% alloy) 0.75%; calcium tin (10% alloy) 0.5% added both together	Mixed fracture, non-homogenous; very inferior to alloy minus deoxidizer Yellowish area in center of bar, dense grayish area surrounding the center spot. Gates when broken showed uniform fracture.

A number of other deoxidizers were tested with the result that in the case of the above alloy it was found that the addition of a maximum of 2 oz. of 15% phosphor-copper to each 100 lb. of alloy gave best results.

An alloy frequently specified by engineers is the following:

	Per cent
Copper.....	82.00
Tin.....	12.00
Zinc.....	6.00

When this alloy is cast, yellow spots will invariably be found in the fractured surfaces, showing the alloy is not one to come homogenous, but the specifications always include "the fracture must be homogenous," because it has been found that in the majority of cases the fracture is not homogenous, but no one appears to think this may be the fault of the alloy itself.

Segregation.—Many tests were made by the author on this alloy. In one case, a bar 1.25 inches square and 6 inches long when broken was found to contain a large T-shaped spot in the center. The yellow part was usually scattered throughout the fracture, but in this case it was concentrated into one spot, and an analysis could be made, both of the yellow spot and the surrounding gray metal (the normal fracture). The result of the analysis was as follows:

Analysis of certain parts of test bar

	Yellow portion	Gray portion
Copper, %.....	84.00	82.18
Tin, %.....	8.39	11.94
Zinc, %.....	5.75	5.68

It will be noted the tin content is much below normal in the yellow portion, also there was considerable loss which was no doubt due to oxides.

A microscopic examination of the yellow spot and the gray spot was then made, the specimens being taken from just below the slices cut off for analysis. A magnification of 100 diameters showed the gray fractures to have a normal structure with few cavities (black spots). There was present a considerable quantity of the hard, blue eutectoid, between the alpha grains which had the usual cored structure. The metal with the yellow fracture showed no eutectoid, but in its place were cavities, probably containing more or less oxide. The specimens were examined, both etched with ammonia and hydrogen peroxide and unetched; the black cavities showed equally well on the etched and the unetched sections. When the composition of the alloy was changed so that only 2% of zinc was contained, instead of 6%, no trouble resulted from the yellow spots. It was assumed that the alloy with 6% was lacking in eutectic at the moment of solidification, therefore the portion that last solidified (in the center of the bar), was minus eutectic, being an incomplete alloy as shown by the analysis. The addition of 1.5 oz. of 15% phosphor-copper, added to the charge of copper while solid, was found effective in reducing the oxides; with 3% of zinc, the tendency to voids was greatly lessened; but with 12% tin, a reduction to 2% zinc is advisable with an alloy of this character.

Melting furnaces.—In melting this class of alloys all of the various types of furnaces shown in preceding chapters are employed. An electric furnace known as the Baily finds favor in some foundries, and is shown in figure 62, which is a part view of the Lumen Bearing Co., Buffalo, New York, melting various alloys, particularly steam metals and red brass. This furnace differs from that depicted on figure 31, and also that shown by figure 64, in that it has no electrodes, the heating element being a "resistor" of granular carbon in a trough as shown by figure 63. This granular material becomes heated to a high temperature by the passage of the

electric current, owing to its resistance to the current, and the heat is thrown onto the roof of the furnace, and is deflected back to the metal at the bottom of the well or trough as in figure 63. Figure 64 is an arc furnace of a type similar to that shown in figure 31, with the difference that while the latter oscillates back and forth, the Booth electric furnace shown in figure 64 revolves completely while melting, and the metal has to be poured from one end of the furnace as shown,

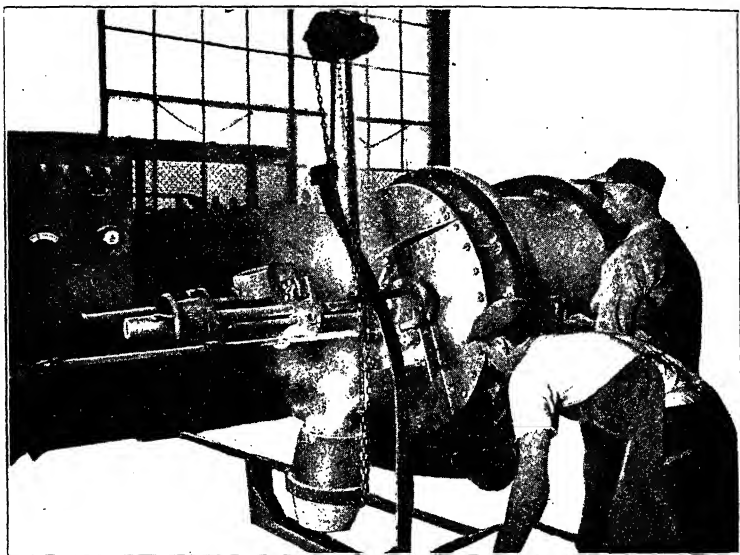


Figure 64.—Booth rotating electric furnace.

instead of having the spout on the periphery of its drum-like body.

An ordinary wind (natural draft) coke-fired crucible pit furnace is shown on figure 65. These are extensively used.

ALLOYS OF COPPER WITH OTHER METALS

In preceding chapters the alloys of copper have been described, which, on account of their easy preparation and the larger proportion of the metals that are combined with the copper, are in general use. There are, however, a number

of other copper alloys, which, though at present seldom employed, possess properties deserving attention. They are as follows:

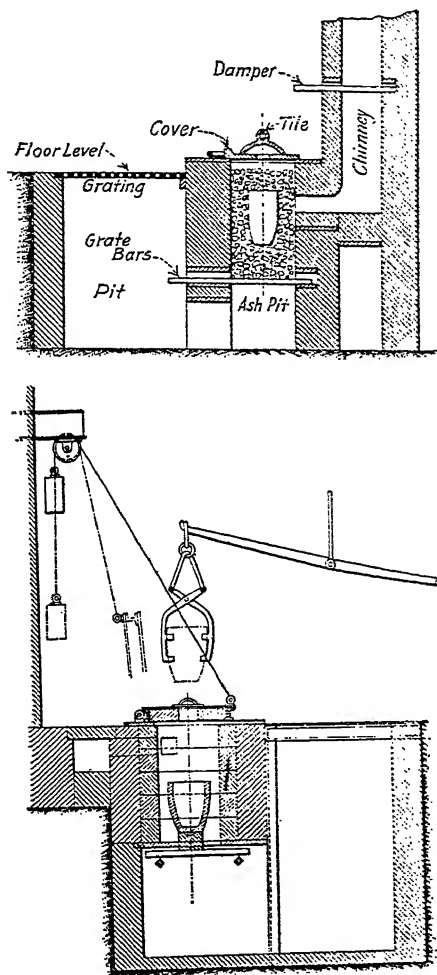


Figure 65.—Types of wind (natural draft) brass melting furnaces.

Copper-arsenic alloys.—Arsenic imparts to copper a beautiful white color, great hardness, and brittleness. Before German silver was invented, these alloys known as “white

copper," "white tombac," "argent haché," "Chinese pétong, etc., were sometimes used for the manufacture of cast articles which were not to come in contact with iron. On exposure to the air, these alloys, however, retain their white color for a short time only, and acquire a brownish tinge. On account of this, as well as the poisonous character of arsenic and the difficulty of working them, these alloys are little used at the present time.

Copper-lead alloys.—An addition of lead to copper renders it softer and more ductile. Alloys of copper and lead are subject to separation or liquation, the lead separating out and leaving the copper in a porous mass, especially if the alloy is not quickly solidified. In preparing the alloys, the copper is melted under a cover of charcoal dust; the fire is then made as hot as possible, and the lead quickly introduced into the overheated copper. As soon as all is melted, stir several times with an iron rod to make the alloy homogenous, and quickly pour the liquid mass into cold metal molds. On account of the liquation characteristic it is difficult to obtain large castings of these alloys faultless, hence they are cast into thin plates, which are subsequently rolled out into sheets. The alloy forms a metal of gray color, brittle, and of feeble affinity.

Alloys of copper and lead.—These were formerly known as "pot metals," and they were classified further as "wet pot metal" and "dry pot metal," according to whether the lead content was sufficient to cause it to ooze from the castings (wet) or was kept under this point. Graham gives the following alloys as pot metals:

Analysis of pot metals

Name	Copper, %	Lead, %
Red, ductile alloy.....	88.00	12.00
Dry pot metal.....	80.00	20.00
Dry pot metal or cock alloy.....	73.00	27.00
Dry pot metal or cock alloy, very short	70.00	30.00

Sometimes a little tin was added to improve the alloy; arsenic was also frequently added to "hold in the lead." These alloys were used for faucets. At the present time, heavily leaded alloys are used for bearing purposes, and there are very few brass-foundrymen who do not possess a cherished "secret" method for holding in the lead with copper. About the best method, though, is to use mixtures of metallic sulphates and salt, borax, and soda ash as fluxes. For leaded alloys containing tin, such as plastic bronze, the tin holds in the lead. Occasionally, though, the tin needs a little assistance, and for this purpose there is nothing better than a mixture of barium sulphate with 10% of calcined borax, used as a flux in the proportion of 2%—half with the cold metals, and half when melted. Alloys containing nickel are useful in holding in the lead in leaded bearing alloys; but even so, the addition of the aforesaid flux will do no harm.

As a bearing alloy for gas-engine bearings the following is frequently used with excellent results:

Bearing alloy

	Per cent
Copper.....	64.18
Lead.....	32.00
Tin.....	3.00
Nickel.....	0.82

It should always be remembered that the nickel should be added in the shape of an alloy of nickel, tin, and copper, properly deoxidized. An addition of 2.50% of this alloy will give the proper amount of nickel.

Plastic bronze.—This noted alloy was devised as the result of experimental work carried out by G. H. Clamer, vice-president and secretary of the Ajax Metal Co. of Philadelphia, Pennsylvania. Its composition is approximately as follows:

Plastic bronze

	Per cent
Copper.....	64.00
Tin.....	5.00
Lead.....	30.00
Nickel.....	1.00

The nickel should be added as an alloy to get the best results.

Where greater compressive strength is required, the lead is decreased as follows:

<i>Bearing bronze</i>	
	Per cent
Copper.....	73.00
Lead.....	20.00
Tin.....	7.00

Alloys of lower lead and higher tin content have been discussed under Bearings.

Plumbic bronze.—The success of plastic bronze led to many imitations, one of these being plumbic bronze, an analysis of which gave the following:

<i>Analysis of plumbic bronze</i>	
	Per cent
Copper.....	69.20
Lead.....	26.10
Tin.....	1.50
Iron.....	1.20
Manganese.....	1.70

Piston packing rings.—For these rings considerable quantities of a 50-50 lead-copper mixture are used. To get the lead to remain in solution with the copper after solidification is considered a problem which is sometimes solved by adding lead sulphide (galena); some add roll sulphur, others use fluxes containing metallic sulphates, and others again use manganese dioxide. So many substances are used for this purpose that each can choose his own method without infringing on the rights of others—in fact, in practice it has been found that the same substances is not uniformly successful; one brass-founder may use a certain method or flux for holding in his lead, and experience great success, while another will find the method worthless. For this reason no special methods will be detailed here.

As remarked before, nickel is frequently used in leaded bearing alloys to advantage, and examples of bearing alloys containing nickel are the following:

Nickel alloy for bearings

	No. 1	No. 3
Copper.....	70.00	60.00
Lead.....	20.00	30.00
Tin.....	5.00	5.00
Nickel.....	5.00	5.00

Add the nickel in the form of a 50-50 copper-nickel alloy, properly deoxidized.

Manganese alloys.—Manganese may also be used in bearing alloys to advantage, the only difficulty is that it is usually associated with iron which segregates as a carbide of manganese and iron; intensely hard, which will score the bearings.

Copper-iron alloys.—In ancient times, copper-iron alloys in the form of black copper appear to have been employed for castings. A statue of Buddha from Hindustan, about 3500 years old, contains, according to Forbes, 91.502% copper, 7.591% iron, 0.021% silver, 0.005% gold, 0.079% arsenic, 0.510% sulphur, 0.292% insoluble matter and traces of nickel and manganese. An alloy of 2 parts copper and 1 part iron possesses great strength, which decreases with an increase in iron, while the hardness increases. An addition of 3 to 4% of copper to malleable iron gave, according to Höltzer, with decreased strength, an elongation of 22.5%, and a decrease in the cross-section of 51%. According to Billings, iron with 2% of copper gives a very red-short, dark-gray, granular alloy. However, according to later investigations by Ball and Wingham, copper in iron is not so dangerous as generally supposed, and the red-shortness ascribed to copper may be due to sulphur in the ores. These investigators found cuprif-erous steel stronger, but harder, than steel from copper.

Copper-steel.—Some years ago, Henry Schneider, of Creusot, France, took out patents for the manufacture of alloys of iron and copper, and steel and copper. In the patent specifications it is stated that the alloy of cast iron and copper can be made in a crucible, cupola, or open-hearth furnace.

The furnace is charged with copper scrap and cast iron mixed between layers of coke, or if a cuprous coke be employed then the cast iron is laid in alternate layers with it, and a layer of anthracite is preferably laid over the whole. The alloy thus formed contains,

generally, from 5 to 20% of copper, according to the purpose for which it is to be employed, and it is remarkable for its great strength, tenacity and malleability—properties which may be still further developed by chilling or tempering.*

The alloy thus formed is charged into the bed of a furnace, with the ordinary ingredients used in the manufacture of steel, preferably under a layer of anthracite, to avoid oxidation. It is important that the copper be introduced at as early a stage in the process as possible. The said alloy may be introduced either while melted or in its hardened condition; or it may be prepared in the furnace itself, where the operation of manufacturing the steel is carried on. In the latter case, the bed of anthracite is first prepared and the copper placed thereon with a suitable quantity of cast or pig iron. The whole is then covered with anthracite, in order to protect the metal from contact with the air during fusion. When the charge is melted, the excess of anthracite is removed and successive charges of iron or scrap added, the operation being then continued in the ordinary way, care being taken to protect the bath from oxidation continually by means of a layer of slag or cinder, which may be renewed as required; also to prevent red-shortness in the metal before the final introduction of the re-carbonizing and manganiferous silico-spiegel iron or ferro-manganese. The steel produced by this means contains from 2 to 4% of copper.

It is stated in the patent specifications that the steels alloyed with copper are especially useful in the manufacture of ordnance, armor-plate, gun-barrels, projectiles, and for other military purposes, or in the manufacture of commercial bars, sheets, etc.

In view of the remarkable elastic limit of copper-steel, while maintaining at the same time a very considerable elongation, F. Lynwood Garrison was of the opinion that it would not be surprising if its use became extensive in the arts. It has the advantage over aluminum, nickel, and tungsten steels in being cheaper to manufacture.

* U. S. patent 415,656, Nov. 19, 1889.

Copper-tungsten alloys.—Copper and tungsten unite, according to Biermann, to an alloy with 10% tungsten, which combines hardness and elasticity with toughness, and is suitable for axle bearings and telegraph wires. Tungsten-copper combines also with other metals. Biermann prepared an alloy with 66 parts of iron, 23 parts of nickel, 4 parts of tungsten, and 5 parts of copper. According to Pufahl, Biermann's tungsten bronze contains 95.39% copper, 3.04% tin, and 1.57 of tungsten.

Copper-antimony alloys.—Melted together in equal parts, copper and antimony give a hard combination of a beautiful violet color suitable for fancy articles.

Mira metal.—The alloy known by this name is distinguished by great resistance towards acids, and is therefore especially suitable for cocks, pipes, etc., which come in contact with acid liquors. Mira metal contains according to analysis: 74.755% copper, 0.615% zinc, 16.350% lead, 0.910% tin, 0.430% iron, 0.240% nickel and cobalt, and 6.785% antimony.

CHAPTER XIV

BRASS FOR ROLLING

THE first account of the alloy of copper and zinc transmitted to the present day was written by Aristotle, who states that a people who inhabited a country adjoining the Euxine Sea prepared their copper of a beautiful white color by mixing and cementing it with an earth found there, and not with tin, as was apparently the custom. Strabo also alludes to the preparation of the alloy of copper and zinc by the Phrygians from the calcination of certain earths found in the neighborhood of Andêra; and other historians, of the time of Augustus, speak distinctly of "cadmia" and its property of converting copper into *aurichalcum*, under which title the zinc alloy was subsequently known. Several writers of the Christian era who have referred to this compound are not more explicit than their predecessors; yet it is evident, from various recent analyses of old alloys, that zinc was contained in many of those prepared about the commencement of the present era.

Zinc and copper.—The influence of zinc upon copper has been referred to several times. It renders copper fit for casting, and the copper-zinc alloys do not show the strong tendency towards liquation peculiar to copper-tin alloys. According to Charpy,* copper-zinc alloys with up to 33% of zinc consists of an aggregation of dendritic (fir-tree-like) crystallites which form solidified solutions of the copper and zinc (mixed crystals of the two constituents) without liquation or disintegration, as is the case with eutectic alloys, having previously taken place. In alloys with 33 to 45% of zinc, crystallites are noticed which are surrounded by a mass,

* Charpy, G., *Etudes microscopiques des alliages metalliques*. Bulletin de la Société d'Encouragement, 1907.

probably of the combination CuZn_2 , consisting of fine crystals. In alloys richer in zinc, two different constituents can also be recognized.

The strength and hardness of copper, are, to be sure, increased to a less extent by zinc than by tin, but its flexibility is far less decreased by it; so that, while copper-tin alloys with about 6% of tin can no longer be worked at the ordinary temperature, copper-zinc alloys with even 50% of zinc can with care be worked at the ordinary temperature, provided they do not contain other bodies which impair their flexibility. If, however, the zinc content exceeds 50%, the alloy becomes rapidly brittle.

On the other hand, many copper-zinc alloys cannot be worked so well at a red heat as some copper-tin alloys; only a few with a fixed zinc content stand working in a heated state, and are malleable. Hence, copper-zinc alloys are, as a rule, worked cold by hammering, pressing, rolling, drawing, etc., and this property of standing such manipulation, without previous heating, is without doubt an advantage. However, like most metals worked cold, they become hard and brittle thereby, and occasional annealing is, as a rule, required to restore to them their lost flexibility.

BRASS, ITS PROPERTIES, MANUFACTURE, AND USES

The manufacture of brass was introduced, in 1550, in Germany by Erasmus Ebener, an artist of Nürnberg, who prepared it by fusing copper with so-called *tutia fornacem* or furnace cadmia. In England, the first brass by the direct admixture of copper and spelter, with or without the inclusion of calamine, was made in 1781 by James Emerson, who took out a patent for the process.

Characteristics of brass.—Generally speaking, brass should contain only copper and zinc; but most varieties on the market contain small quantities of iron, tin, arsenic, and lead. In many cases these admixtures are due to these minerals being in the ores from which the copper or zinc is extracted; while in others they have been intentionally added in order to change

the ductility, fusibility, etc., of the alloy. Copper and zinc can be mixed together within very wide limits, the resulting alloys always being serviceable.

Color.—Generally speaking, it may be said that with an increase in the copper content the color inclines more towards a golden, the malleability and softness of the alloy being increased at the same time. With an increase in the zinc content the color becomes lighter and lighter, and finally shades into a grayish-white, while the alloys become more fusible, brittle, and at the same time harder. Just as different as are the properties of the respective alloys so is the cost of production, the price of brass increasing with the greater copper content. Extensive investigations have been made into the effect of additions of zinc on the color of copper. Thus, the addition of 5% of zinc affects the red color of copper very little; when 10% is added the color becomes a true bronze; with 15%, a light orange shade; with 20%, a greenish-yellow; from 20 to 25% the color changes very little, and these alloys are included under the term "green gold"; brass with 30% zinc has the true yellow brass color, and this is continued to 35% zinc; at 38% the color begins to change again from yellow to a reddish-yellow shade; at 45% the color is a rich golden; at 55% the color resembles 14-carat gold; and at 60% the brass begins to whiten, and the alloys get brittle and are of no value for castings.

Structure, ductility, melting point.—The physical properties of alloys of copper and zinc differ very much according to the quantities of copper and zinc contained in them. Alloys containing up to 35% of zinc can be converted into wire or sheet, in the cold only, those with from 15 to 20% being the most ductile.

Brass always shows a crystalline structure, which is the more pronounced the more brittle the alloy is, hence, that prepared from equal parts of copper and zinc shows the most distinct crystalline structure.

If a very ductile brass is to be prepared, great care must be exercised in using metals of the utmost purity, since exceed-

ingly small admixtures of foreign metals suffice to injure the ductility considerably, rendering the fabrication of very thin sheets or fine wire impossible.

A very important factor in brass is its melting point, there being wide deviations in this respect, which are readily explained by the great difference in the melting points of the two constituent metals. Generally speaking, the fusing point of brass is about 1030° C. (1886° F.). If brass in a fused state is kept for some time in contact with air, its composition undergoes an essential change by the combustion of the greater portion of the zinc contained, which explains the change of color frequently observed in brass fused for some time in contact with air.

Scrap copper in brass.—Old copper from worn-out copper articles is frequently used in the manufacture of brass, but such copper generally contains foreign metals such as solder, etc., which may exert either a favorable or an injurious influence upon the properties of the brass. Lead, tin, and iron are the most frequent contaminations. If the brass is to be used for castings, their injurious influence is not so great as in the manufacture of thin sheet or wire. Up to 2% of lead is frequently added to brass intended for castings, such making the alloy somewhat harder, and at the same time depriving it of the disagreeable property of fouling the tools in working, which is of special importance in filing and turning. In casting brass containing lead, care must, however, be taken to cool the castings very rapidly, otherwise the lead readily separates in the lower portion of the casting and produces unsightly spots.

A slight addition of tin makes the brass more fusible, somewhat denser, and take a better polish. The presence of a small quantity of iron increases the hardness of brass considerably, but such brass, on exposure to the air, is easily stained by rust.

Uses of brass.—In the arts, brass is commonly employed in the construction of scientific apparatus, mathematical instruments, small parts of machinery, and for many other purposes.

A distinction is generally made between sheet brass used in the manufacture of wire and sheets and cast brass, which requires no further mechanical manipulation than turning and filing. A number of alloys are sold on the market under various names, but, as regards their composition, they must be included in the generic term "brass," though some of them are especially adapted for certain purposes.

Especially pure metals, as free as possible from foreign elements injurious to ductility (bismuth, antimony, arsenic, tin, lead, iron) must be used for sheet brass, for the manufacture of sheet and wire. Sheet brass, to be made very thin under the hammer—the best quality of German sheet brass for musical instruments, for example—contains, as a rule, 19 to 21% zinc; sheet still suitable for most purposes, 22 to 30%; and sheet for toys and articles easily shaped 30 to 40%. Brass for wire requires similar composition.

Antimony in brass.—For the purpose of investigating the influence of antimony on the cold-shortness of brass, E. S. Sperry prepared brass plates from the best quality of Lake copper and refined zinc with varying quantities of antimony, and tested their behavior in rolling and by the condition of their fractures. The hardest alloy of 60% copper and 40% zinc was selected so that the influence of the addition of antimony should be more apparent, and the quantities of antimony amounted to 0.01, 0.02, 0.05, 0.1, and 0.65%. While Kerl states that 0.001% of antimony in copper renders the brass unfit for wire and sheet, Sperry found that brass with 0.006%—hence from copper with 0.01%—antimony could be satisfactorily rolled; with the softer alloys the influence of the same quantity of antimony is said to be still less injurious. A content of 0.02% antimony could be readily recognized by the condition of the fracture. As some brands of electrolytic copper contain from 0.001 to 0.08% of antimony, and are generally used for brass without being previously tested, the objections of some manufactures to such copper are readily explained.

Filings and turnings always contain small quantities of

iron particles, and so are not suitable as an addition to the better qualities of brass. Silesian zinc, as a rule, contains not less than 0.75% of lead. Missouri zinc is very pure; so is Spanish zinc—R. C. A. Refinado brand—the latter being free from arsenic, antimony, and sulphur, and contains only 0.05% lead and a trace of iron. It is used for the best quality of sheet brass (cartridge shells). The more sheet brass is to resist the action of acid and alkaline fluids the richer in copper it should be; and accordingly, the following proportions of copper to zinc may be recommended: 70: 30; 66: 34; and 60: 40. Brass for cartridge shells contains 72 parts copper and 28 parts zinc, with at the most 0.25% of lead, or still better entirely free from it.

Brands of copper.—The best evidence of the quality of a brand of copper is that it yields brass suitable for the preparation of thin sheet and wire, and the sharpest test for the quality of the copper consist in that when the brass is drawn out to tubes over a core-bar, the tubes show no cracks. The following analyses show the composition of a number of old, but interesting alloys of brass used for sheet and wire:

TABLE 38.—Composition of antique brass

Brass	Place	Copper %	Zinc %	Lead %	Tin %	Sili- con %	Anti- mony %	Iron %
Sheet.....	Jemappes.....	64.6	33.7	1.4	0.2			
".....	Stolberg.....	64.8	32.8	2.0	0.4			
".....	Romilly.....	70.1	29.26	0.28	0.17			
".....	Rosthorn (Vienna)...	68.1	31.9	Trace				
".....	".....	71.5	28.5					
".....	".....	71.36	28.15					
".....	".....	71.10	27.6	1.3				
".....	Iserlohn and Romilly.	70.1	29.9					
".....	Lüdenscheid.....	72.73	27.27					
".....	" (brittle).....	63.66	33.02	2.52	.....	0.61		
".....	Hegermühl.....	70.16	27.45	0.79	0.20			
".....	Oker.....	69.98	29.54	0.97	.....		0.79	0.23
Wire.....	England.....	70.29	29.26	0.28	0.17			
".....	Augsburg.....	71.89	27.63	0.85				
".....	Neustadt-Eberswalde.	70.16	27.45	0.20	0.79			
".....	".....	71.36	28.15					
".....	".....	71.5	28.5					
".....	".....	71.0	27.6					
".....	".....	65.4	34.6					
".....	".....	65.5	32.4	2.1				
(Good composition for sheet and wire).....								
	Chinese, best quality brass.....	67	32	0.5	0.5			
	Chinese, ordinary qual- ity brass.....	10	5					
		10	2.7					

Brass rolling-mill alloys.—The subject of modern brass rolling-mill alloys was fully discussed by R. A. Wood before the 11th Convention of the Institute of Metals,* at Boston in 1916, from which the following excerpts have been taken:

By far the greater proportion of brass rolling-mill alloys are made up from straight copper and zinc mixtures, which, with the addition of a small quantity of another metal or metals, constitute the majority of the brass rolling-mill alloys. The fabrication of some of these alloys is a simple matter, while others require an amount of skill and ingenuity only acquired by long practice.

Copper and its alloys readily absorb sulphur, which has a tendency to cause the metal to become spongy and porous in spots; and if sulphur is present in any considerable quantity it will cause the metal to become brittle and break up during fabrication. The absorption of sulphur takes place during the melting operation, and is caused by the metal not being properly protected from the gases of combustion. Care should be taken to select a fuel as free from sulphur as circumstances will permit. Charcoal, when broken up into fine pieces, has the property of absorbing sulphurous gases, so the metal should be protected by a good covering of charcoal while melting. A mixture of approximately 50 parts copper and 50 parts zinc represents the highest proportion of zinc the alloy may contain and still be workable. It is possible to roll such an alloy into a sheet or draw it into a wire, but the operations are so tedious as to limit their being carried out on a commercial basis. This alloy is commercially used as either "fine" or "long-grain" spelter solder, and is used for brazing purposes.

Alloys consisting of 57 to 63 parts of copper and the remainder zinc are used in the extruding process for making rods, tubes, and shapes of varying cross-sectional area. The extruding process is carried out hot; but the work is, as a rule, given one or two cold-finishing operations on a draw-

* *Journal Institute of Metals*, vol. xi, Sept. 1917, p. 181.

bench. Mixtures of this class may also be rolled hot, and are representative of the commercially hot-worked alloys.

A mixture of 60 parts copper and 40 parts zinc is about as cheap an alloy as can be successfully worked cold; although there are mixtures composed of from 57 to 59 parts copper and 43 to 41 parts zinc which may be rolled into sheets or drawn into wire. Alloys of this class are mostly used for hard soldering purposes. The successful working of such alloys depends primarily upon the skill with which the casting operation is carried out. Alloys containing a high percentage of zinc, do not, as a rule polish nicely, as the surface of the metal is more or less likely to have a pitted and streaked appearance.

Annealing.—Extreme care must be taken in annealing these alloys, and the operation must be entrusted to a competent workman. The alloys high in zinc are likely to “run” in places if slightly overheated. These alloys are very soft and pliable at a red heat, but on cooling they become somewhat hard and springy. If they are plunged into a tank of water immediately after being removed from the annealing furnace they will remain much softer than if allowed to cool gradually. This is a more or less risky procedure, for if the plunging temperature is not just right, some of the metal will split and crack. Such cracks are known as “water-cracks,” and they must not be confused with “fire-cracks,” which they closely resemble. If the hot metal is cooled by means of a stream of water, such as is thrown from a hose, it will cause water-cracks; but if the cooling operation is carried out by means of a fine overhead spray of water this difficulty will be practically obviated.

Fire-cracks may be said to be of a mechanical nature, and are caused by an unequal stress within the metal itself; as the metal is heated in the annealing furnace, this internal stress causes an unequal expansion of the metal which has a tendency to cause it to pull apart. A metal that has been thoroughly “worked” seldom fire-cracks.

Season cracking.—Season-cracks may be said to correspond to delayed fire-cracks, and are caused by the gradual equalization of strains within the metal. However, overworked metal will, in some instances, develop season-cracks. The grade of metals used in the alloy, the melting practice, and the mechan-

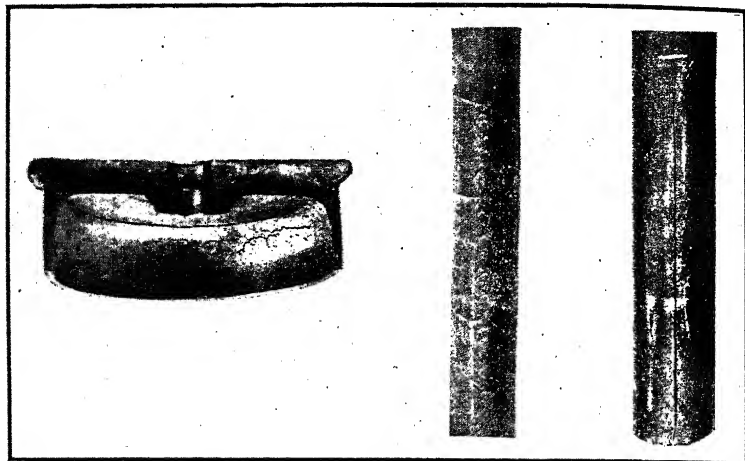


Figure 66.—Examples of season cracking of brass.

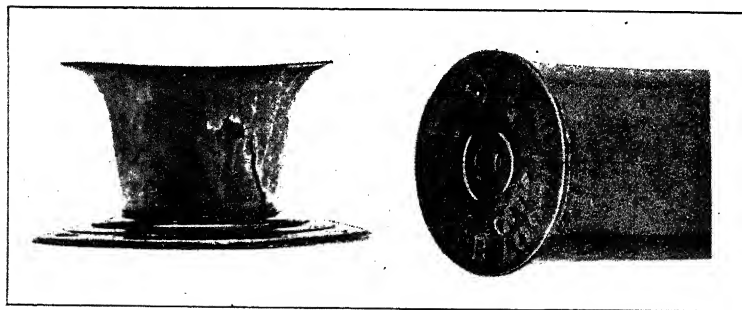


Figure 67.—Other examples of season cracking of brass.

ical operations applied to the metal, all more or less contribute to the cause of season cracking. Examples of season cracking are shown in figures 66 and 67, taken from the paper on the season cracking of brass and other copper alloys presented before the British Institute of Metals, March 10, 1921, by H. Moore, S. Beckinsale, and Clarice E. Mallinson. They

concluded that season cracking occurs only in material which is maintained in a state of stress, either by external constraint, or more commonly by internal stress. They further stated that season cracking may occur in brass protected by successive layers of such a protective coating as lacquer. Also that nickel-plating is probably completely effective in preventing season cracking, if a sufficient and continuous coating of nickel is secured.

The following binary alloys of brass are given by Wood in his paper, previously mentioned:

TABLE 39.—*Binary alloys of copper and zinc. (After Wood)*

Trade name	Copper, lb.	Zinc, lb.
Brazing or hard solder.....	50	50
Extrusion brass.....	55	45
Extrusion brass: soldering or spelter wire.....	57	43
Soldering or spelter wire (worked cold).....	59	41
Muntz metal; yellow metal.....	60	40
Check brass (baggage checks).....	62	38
Cutlery brass (knife linings).....	63	37
Hoop brass (pail hoops, etc).....	64	36
Common brass; market brass.....	65	35
Pin wire.....	65	35
Drawing brass; dipping brass.....	66	34
Shrapnel brass.....	67	33
Clock-case metal (extra spinning brass).....	68	32
Cartridge brass.....	70	30
Spring brass (extra quality).....	72	28
Brazed brass tubing, extra quality.....	75	25
Common low brass.....	80	20
Good low brass.....	83	17
Best low brass.....	85	15
Medal metal.....	86	14
Bronze (regular).....	88	12
Rich or best bronze.....	90	10
Goldline.....	90	10
Gilding.....	93	7
Percussion cap gilding.....	95	5
Primer cap gilding.....	97	3
Copper strips.....	97	3
Copper (brass mill).....	99	1

The proportions given above do not represent the analysis of the alloys, but are the weights used by the casters in making up their heats.

The straight copper-zinc alloys containing more than 65% of copper, if properly worked, seldom cause trouble due to water, fire, or season cracking.

Coarse-grained alloys.—Metals which have been properly cast and rolled or drawn, should, if rightly annealed, have a good surface and a close grain; and it may be safely assumed that in almost every instance when a porous, open, or coarse-grained metal is encountered, the trouble is in the annealing operation:

The binary alloys are all of a tough and tenacious nature, and difficult to work under a tool for milling, turning, drilling, or engraving purposes. In order to impart free working qualities, a certain amount of lead is used in mixtures for brass to be worked. The lead, remarked Wood, impairs the cohesive qualities of the alloys, and metal containing lead will not stand as great a reduction without cracking as will the alloys free from lead. Also, leaded alloys do not have as close a grain as those free from lead, consequently they do not polish up as well. The following are ternary alloys of copper, zinc, and lead:

TABLE 40.—*Ternary alloys. (After Wood)*

Trade name	Copper, lb.	Zinc, lb.	Lead, lb.
Extruded rod (free turning).....	56.00	42.00	2.00
Extruded shapes.....	56.00	40.00	4.00
Collet brass (clock work).....	58.00	39.50	2.50
.....	60.00	37.00	3.00
Clock brass (wheels and frames).....	62.00	36.50	1.50
.....	64.50	35.50	1.75
Brass rods (free turning).....	63.00	35.00	2.00
.....	64.00	35.00	1.50
Die-sinkers' and engravers' brass.....	65.00	33.00	2.00
..... brass.....	66.00	33.00	3.00
Clock brass.....	67.00	33.00	0.75
Watch brass.....	68.00	32.00	2.00
Balance wheels (clocks).....	70.00	30.00	2.00
Blazed tubing (for threading).....	72.00	28.00	1.00
.....	75.00	25.00	2.00
Screen plates.....	76.00	22.00	2.00
Low brass (turning rod).....	80.00	20.00	1.00
“ “ (free cutting).....	83.50	15.50	1.50
“ “ (kick-plates).....	85.00	15.00	1.00
Extruding bronze.....	87.50	10.00	2.50
Bronze (engravers' leaded).....	88.00	12.00	1.00
“ (free cutting).....	89.00	9.50	1.50
“ (hardware).....	90.00	10.00	0.75
“ (screw wire).....	95.00	5.00	0.50

The above mixtures give the charges as weighed off by the casters, and do not represent the analyses of the alloys.

Close-grained alloys.—When a very tight, close-grained metal, high in tensile strength is required, an addition of tin is made to the base mixture. These alloys must be carefully handled when casting, otherwise the surface of the finished material when dipped or polished will show numerous fine, white streaks, and in some instances, slivers. The metal must not be heated higher than necessary, and the tin should be pushed under the surface of the metal as quickly as possible, shortly before it is poured. The mixture is then thoroughly stirred. Alloys containing tin seem to develop season-cracks much quicker than some of the other mixtures, and this is especially true of the spring-tempered brasses.

Tin-bronze for rolling.—A number of alloys are made from a straight copper-tin mixture, and these are known under the trade name of "tin-bronze." Alloys containing a small amount of tin (1 or 2%), will not be found difficult to roll; but the mixtures containing from 5 to 10% are not only difficult to cast properly, due principally to piping, but the rolling operation must be carried out most carefully. An experienced rollerman is necessary. The skill is to gradually get the grain of the metal started right, and after this has once been accomplished no further difficulty will be experienced with the rolling operation.

Care must be taken not to overheat the metal during annealing, and it should not be brought to a much higher temperature than a dull cherry-red color, after which it is allowed to soak in the furnace until it has attained an even heat throughout its entire mass.

These copper-zinc-tin mixtures, when drawn into wire, are sometimes hard in spots, and such spots are more or less brittle compared with the remainder of the coil of wire. Such hard spots are generally due to overheating during annealing, the coil of wire being "burnt" in places.

The addition of a small amount of phosphorus—generally in the form of phosphor-tin or phosphor-copper—greatly sim-

plifies the casting operation, as it tends to reduce the oxides and causes the molten metal to become more fluid, and produces a more solid and malleable, as well as a more ductile casting.

Alloys of this class are generally put on the market under the name of phosphor-bronze, and each mill has its own mixtures, there being no particular standard. As a rule, the phosphorus is added to the mixture shortly before it is ready to be poured.

Many manufacturers do not believe in adding phosphorus to mixtures containing zinc, claiming it has a tendency to produce fine pin-holes in the castings. This idea, however, is not held by all, as the following mixtures will indicate:

A		B	
	Pounds		Pounds
Copper.....	98.75	Copper.....	98.00
Tin.....	1.20	Tin.....	1.00
Stick phosphorus.....	1 stick	Zinc.....	1.00
		5% Phosphor tin.....	0.50
C		D	
	Pounds		Pounds
Copper.....	93.00	Copper.....	88.00
Tin.....	4.50	Tin.....	None
Zinc.....	2.00	Zinc.....	12.00
5% Phosphor tin.....	0.50	15% Phosphor copper.....	0.50

The addition of too much phosphorus must be avoided as it will not only cause pin-holes, but increase the difficulties of rolling due to cracking. In table 41 following are some of the alloys containing tin.

Dense grain.—For certain classes of work the trade calls for a metal having a very dense grain, and exceedingly high in tensile strength, and for alloys of this class iron is added to the mixture. These alloys shrink excessively in cooling when cast, and unless the melting and pouring operations are skillfully carried out the castings will pipe. Also, the iron must be properly introduced or it will segregate in small nodules, hard as steel. It is customary to make a hardening alloy of copper, iron, and scrap clippings from horse nails, give excellent results for this purpose. A little manganese in the form of manganese copper greatly improves the alloy. The copper-iron manganese alloy may vary considerably in

different mills, but one alloy successfully used is made of 86 lb. of copper, 4 lb. of manganese metal, and 10 lb. of horse-nail scrap. This makes the 10% iron alloy.

TABLE 41.—Copper-zinc-tin alloys. (After Wood)

Name	Copper, lb.	Zinc, lb.	Tin, lb.
Hot forging alloy.....	60.00	40.00	0.75
" " ".....	60.00	39.50	1.50
" " ".....	61.00	40.00	0.50
" " ".....	61.00	39.00	0.75
Spring brass.....	62.00	37.00	0.75
Spring rods.....	63.00	37.00	0.50
Bell metal.....	65.00	35.00	0.75
Spring wire.....	67.00	33.00	0.25
Reed tongues.....	69.00	30.00	1.00
Condenser tubing.....	70.00	29.00	1.00
Special cartridge.....	72.00	28.00	1.00
Spring brass (extra quality).....	75.00	24.00	1.00
Low brass spring metal.....	81.00	18.00	1.00
Low brass dipping metal.....	83.00	17.00	0.75
Pen metal.....	85.00	13.00	2.00
Medal metal.....	86.00	14.00	0.25
Watch fob metal.....	87.50	12.00	0.50
Oreide metal.....	87.25	11.50	1.25
" ".....	89.00	11.00	1.00
Bronze (high color).....	90.00	10.00	1.00
Bronze (shaft wire).....	90.00	7.00	3.00
Bronze, small shells.....	93.00	7.00	0.50
Bronze chain.....	94.00	1.25	4.75
Medal metal (rich color).....	95.00	3.00	2.00
" " " ".....	97.00	1.00	2.00

These mixtures containing iron are similar to the other ternary alloys, but iron is added in place of tin, the amount varying from 0.25 to 2%.

In the builder's hardware trade a metal is frequently demanded that must be both free turning and close-grained, and this condition is met by adding both tin and lead to the copper-zinc alloys. These mixtures, however, are brittle at a red heat, and extreme care must be taken in handling them. The iron molds have to fit absolutely tight, otherwise trouble will result from shrinkage cracks which have their origin in the fin or burr on the castings. Experienced casters will avoid this trouble by knocking the mold down the moment the metal has set; this eases the strain at the edges of the bars

and prevents their cracking. These mixtures containing both tin and lead must be poured at as low a heat as is consistent with obtaining a good casting. If poured too hot the metal will not only be more difficult to roll but will very likely be "specky" as well.

Formulas for alloys suitable for builders' hardware for rolled material follow:

TABLE 42.—*Alloys for builders' hardware. (After Wood)*

Trade name	Copper, lb.	Zinc, lb.	Tin, lb.	Lead, lb.
Block brass.....	67.50	32.50	0.25	1.50
Hardware bronze.....	88.00	10.00	1.50	1.00
“ “	90.50	9.50	1.37	1.25
“ “	90.00	8.75	0.50	0.75
“ “	90.00	8.00	0.50	1.50
“ “	90.00	8.00	1.50	0.75
“ “	92.50	7.50	1.50	1.25
Engravers' bronze.....	90.00	8.00	1.00	1.00
Screw wire.....	94.50	5.00	1.00	0.50
Die-sinkers.....	86.00	10.00	1.00	3.00

Rolling-mill mixtures are known as "high brass" and "low brass;" the former contains from 60 to 80% of copper, while the latter begins at 80 and runs to 88% copper—above 88% and up to 98%, the mixtures are called "bronzes," owing to their color.

MANUFACTURE OF BRASS—HISTORICAL

Before zinc was known in the metallic form, brass was prepared by fusing copper with zinciferous ores, such as calamine or carbonate of zinc, the zinc reduced by this process combining with the copper to form an alloy. As is well known, the chemical composition of even the purest ores from the same locality varies always somewhat, and it is almost impossible to obtain a mixture of metals of fixed properties and general uniformity. For the sake of completeness this antiquated process of making brass will be briefly described. Manufacturers still working according to it, must, on the

one hand, use very uniform zinc ore, and must also possess a thorough knowledge of the properties of brass, so as to be able to tell from the color and fracture of a sample of the fused mass whether the alloy possesses the requisite qualities, or whether it requires the addition of a further quantity of zinc ore or copper. The production of brass with the use of zinc ores is less expensive, but more tedious and troublesome than by the direct fusion of pure metals.

Old method of making brass.—Before melting, the ores have to be subjected to a preparatory treatment to remove, as far as possible, admixtures of foreign metals such as lead, arsenic, antimony, which would impair the quality of the brass. The native calamine is calcined to expel carbon dioxide, sulphur, and other volatile matter, and forms zinc oxide. The calcined ore is then ground in a mill, the galena contained in it is removed by washing, and the dried ore is mixed with about one-fourth its volume of charcoal. The mixture is put into large crucibles with alternate layers of granulated copper. Powdered charcoal is then thrown over the top, and the crucibles are covered and luted. The old form of furnace consisted of a cone with base downward, and the apex cut off horizontally. The crucibles were placed upon a circular grate or perforated iron plate on the hearth. A sufficient quantity of fuel was heaped around the crucibles, and a perforated cover of bricks or clay was fitted to the mouth, which served as a register to regulate the heat. After the alloy is supposed to be formed—the time varying from 10 to 20 hours, according to the nature of the calamine and the size of the crucibles—the heat is increased, so as to fuse the whole down into one mass. The lid is then thrown up, and a workman, standing over the opening, grasps the crucible with a pair of tongs and lifts it out of the furnace. The refuse is skimmed off, and another workman then seizes the crucible with a pair of tongs and pours the contents into iron molds, guiding the stream with an iron rod. During this process there is a considerable combustion of zinc, the metal burning with its characteristic blue flame. When the material is good, a single

fusion is sufficient; but the finer products undergo a second fusion with fresh calamine and charcoal.

The furnaces used were of peculiar shape and not all of the same type as shown in the illustrations: figures 68 and 69.

The furnace in figure 68 consists of a vault of refractory material, and is about $3\frac{1}{4}$ feet high. At the narrowest place is an aperture through which the furnace communicates with a chimney with good draft. The plate upon which the crucibles

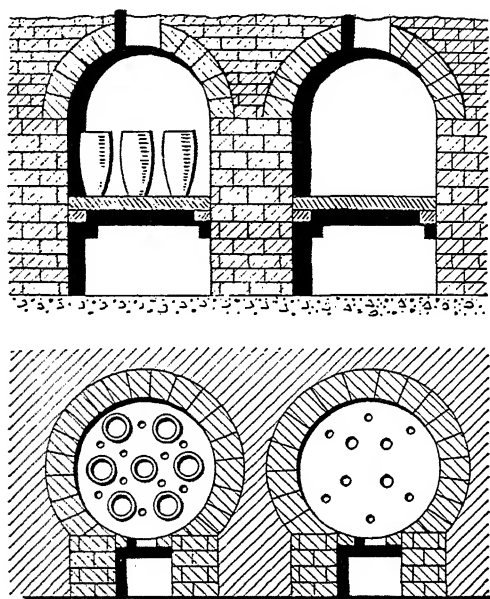


Figure 68.—Old type of brass furnace.

for melting the brass stand has seven apertures so arranged that six of them are in the periphery of a circle, while the seventh forms the center of the circle. Between these larger apertures serving for the reception of the crucibles are smaller ones, which admit the air from below into the furnace. The bottom plate consists of a thick cast-iron plate coated with a layer of fireclay. The six crucibles standing on the periphery have a height of 1.18 feet, with an upper diameter of 0.65 foot, which corresponds to a bottom diameter of 0.55 foot.

The crucible sitting in the center hole is called the king crucible, and being more exposed to the heat is generally somewhat larger; it is, as a rule, 1.18 feet high, with an upper diameter of 0.75 foot. The smaller crucibles hold about 92 to 97 lb. of metal each, and the king crucible about 132 lb.

Figure 69 shows another style of brass furnace. As will be seen, the space in which the crucibles are placed has the form of two truncated cones touching each other with the basis, a shaft being thus formed in which less fuel is consumed than in a furnace having the form of a cylinder. Charcoal was often used in these old-time furnaces in place of coke.

The crude brass may show several defects in regard to its composition; it may either contain too much zinc or copper, or the reduction of the zinc may not have proceeded in a complete manner. In such cases it is possible to improve the alloy by a corresponding addition of copper, zinc ore, or charcoal, and by again fusing it. Sometimes pieces of brass or metallic zinc are also added.

Manufacture of brass by direct fusion of the metals.—At first glance this would appear to be a very simple operation; it has, however many difficulties, and considerable skill is required to produce brass answering determined demands in regard to fusibility, tenacity, etc. In most factories the fusion of the metals is still carried out in natural-draft coal or coke-fired crucible furnaces, of the type shown in figure 65, each holding only one crucible that may contain as much as 300 lb. of metal, and which are removed from the furnace, skimmed, and poured into molds of soft gray iron made in two parts, and held together with wrought-iron bands with wedges in between. Brass for rolling into sheets is cast into flat slabs which will vary in width according to the width of the desired sheet. Brass for rods and wire is cast into cylindrical billets, and for tubes into either solid or hollow cylindrical shapes.

Ingots for wire drawing.—When making ingot shapes of cast brass for rolling, wire drawing, and the other products of a brass mill by the time-honored crucible process, many difficulties are encountered which affect the quality of the

product from day to day. The operation of pouring the brass is most disagreeable and unhealthy on account of the fumes evolved by the zinc and the flux of sodium chloride used in melting the metals. Some of the difficulties are attributable to variations in the working of the furnaces due to the weather; to a gradual loss of efficiency through silting of the flues with furnace dust; to variations in the fuel; to the

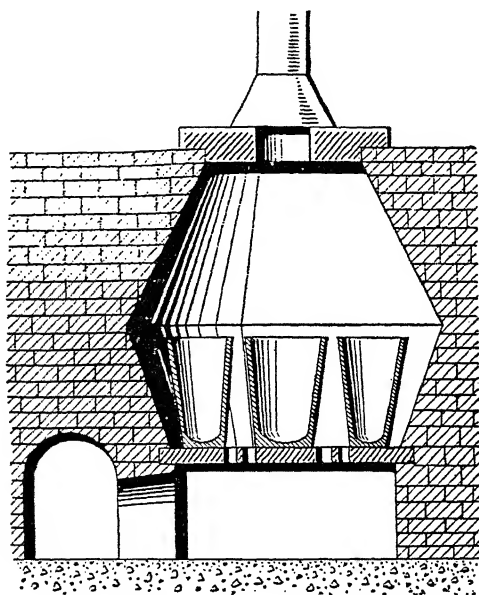


Figure 69.—Brass melting furnace shaped like a truncated cone.

physical changes experienced by the workmen; and to so many other causes beyond scientific control that the entire process was regarded as being unsatisfactory. The advent of the electric furnace and its introduction into the brass industry would appear to offer a solution of many of these difficulties. One of the pioneers in the application of electric melting to the brass mill was the Bridgeport Brass Co., Bridgeport, Connecticut, whose staff sums up the advantages gained by the elimination of the crucible process as follows:

(1) The personal element as far as the actual operation of melting and pouring is concerned, is practically eliminated, because all the factors which enter into the production of brass of a uniform and definite quality are susceptible of exact determination and control. (2) The brass is thoroughly mixed without the assistance of the melter as the furnace mechanically solves this problem. (3) The temperature of the metal is indicated electrically, and personal judgment is not relied upon. (4) The heat input and also the temperature of the brass is always under perfect control, and can be adjusted as desired. (5) The purity of the brass is guarded by the exclusion of the atmosphere during the melting operation. And there are many other notable advantages.

The brass is poured direct from the electric furnaces into the molds, which are of cast iron as before mentioned. At one time it was considered impossible to use iron molds, so molds of granite were used exclusively.

The preparation of these molds (granite) required great care, the following points deserving special attention: The granite plates had to be provided with a uniform coating of clay, which must always be kept in such a condition as to ensure the utmost uniformity in the surface of the plates. To prevent the cracking of the coating of clay, it was covered, after thorough smoothing, with a thin layer of cow dung.

The granite plates thus prepared were arranged in the following manner: The upper plate was suspended over the lower one, the space or mold between the two being limited by iron bars laid on the lower stone, which was a little longer than the upper one, and projected to the front so as to form a lip or mouthpiece for receiving the metal. The plates were bound together with iron, and raised on one side so that they stand at an angle of 45° . As soon as the casting was finished and the metal supposed to be solidified, the sheet of brass was carefully taken from the mold. With sufficient precautions, such granite molds could be used for a long time without the coating of clay becoming damaged, and the sheets would turn out very uniform after the mold had once been heated by

several castings. One and the same mold was frequently used continually, so as to keep it warm, and if it had to stand empty for some time it was wrapped in a poor conductor, such as a coarse carpet to prevent its cooling. If the mold was damaged it had to be carefully mended, and the mended places sharply dried to prevent cracking. The sheets of brass taken from the mold were subjected to a mechanical cleansing, and at the same time carefully inspected, defective sheets being re-melted.

Rolling plates.—At the present time the plate brass obtained by casting is generally worked into sheet brass, which was formerly prepared by hammering, but now by rolling. In some cases rolling is succeeded by hammering, as for instance, in the case of the very thin sheet-brass known as Dutch metal, which is distinguished by the peculiar clear sound it emits on being pressed together. Thicker plates are occasionally prepared for rolling by hammering. After each passage through the rolls the sheets are heated in a furnace, quenched to obtain greater ductility, and then rolled cold until reduced to the desired thickness. In working brass which is only ductile in the heat, the sheets must of course pass in a hot state through the rolls until reduced to the proper size. Before rolling, the sheets, and sometimes the rolls also, are coated with oil. After passing through the rolls the sheet brass is finally subjected to a treatment which decides whether it is to be soft and flexible, or hard and elastic. For soft sheet, the rolled sheet brass is again heated and quenched; while for hard and elastic sheet the heating is omitted, and the sheet rolled cold several times more.

The sheets are generally heated in a reverberatory furnace heated by wood or gas (Siemens regenerative gas type). Coal, if used in such furnaces, yields, on account of the sulphur contained in the gases of the fire, a product which after cleansing does not show a beautiful yellow, but a red color, which is due to the copper having entered into combination with the sulphur in the gases of the fire. If coal is to be used as fuel, either furnaces with iron or clay muffles washed by

the flame are used; or the coal is converted into gases, which, before combustion, are drawn by means of an exhauster through milk of lime to remove their sulphurous acid content. Regenerative gas firing is advisable, especially for large heating furnaces, since by directing the flame first to one side and then to the other, a more uniform heat can be obtained, and the temperature more readily regulated.

Cleansing or pickling of brass.—The finished sheets have a black color, which is partly due to the formation of cupric oxide on the surface and partly to sulphur combinations formed, as previously mentioned, by heating with coal while annealing. As a rule, brass is put onto the market in a bright state, the only exception being the thicker sheets, which retain their black coating. In order to impart to the sheet its characteristic yellow color, it is subjected to a final operation termed “pickling” or “dipping.” This operation simply consists in treating the sheet with acid, which removes the layer of oxide to which the black color is due. The pickling is commenced by placing the sheets in a fluid consisting of 10 parts of water and 1 part of sulphuric acid. The layer of oxide quickly dissolves, and the sheets show the pure yellow-brass color. After this operation, the sheets may be at once washed and dried, and shipped to market.

In most cases the sheets are, however, subjected to a second treatment with acids in order to impart to them a beautiful color; hence the treatment with sulphuric acid is generally termed preparatory pickling. As the actual pickle, either nitric acid alone is used, or a mixture of two parts nitric acid and one part of sulphuric acid. Pickles containing nitric acid possess the property of dissolving zinc from the brass quicker than copper, the surface of the sheet acquiring thereby a warmer tone, shading more or less into reddish. By exercising great care, dilute nitric acid alone may be used as a pickle, but the sheets must be washed immediately, as if only the slightest trace of the acid remains, they acquire after some time a greenish color due to the formation of a basic cupric nitrate.

It has been observed that nitric acid containing a certain quantity of nitrous acid yields especially beautiful shades of color. To obtain them a small quantity of organic substance is added to the nitric acid, or to the mixture of nitric and sulphuric acids. The most curious substances are used for the purpose, snuff, for instance, being highly recommended as especially efficacious in producing beautiful colors. The use of such substances is, however, entirely superfluous, there being a number of cheaper organic materials, which, when brought together with concentrated nitric acid, evolve nitrous acid. The cheapest of these is dry sawdust, the nitric acid acquiring an orange-yellow color a short time after its introduction, which is due to the products of decomposition of the nitric acid, prominent among which is nitrous acid. After taking the sheets from the pickle they are washed, best in running water, in order to remove the last traces of acid.

By quick pickling, the articles are obtained bright by the removal of the layer of oxide from the smooth surface of the metal. But sometimes a dull lusterless surface is to be imparted to the brass, which is effected by treating the articles with a boiling pickling fluid also composed of nitric and sulphuric acids. In many factories this pickle is prepared by dissolving 1 part of zinc in 3 parts of nitric acid, and mixing the solution with 8 parts each of nitric and sulphuric acids. The solution is heated in a porcelain dish, and the articles to be pickled is dipped in it for 30 to 40 seconds. In dipping the brass articles, dense red-brown and pungent vapors are evolved, which, if breathed, are suffocating. The operation should therefore be done under a chimney with good draft; or, still better, in an open space.

The pickled articles have a gray-yellow color, and in order to bring out the pure yellow color they are immersed for a few seconds in pure nitric acid. They are then drawn through a weak solution of soda or potash, and finally washed. As the bright metal loses its beautiful color by oxidation on exposure to the air, the articles, after drying, must be coated with good varnish.

CHAPTER XV

BRASS FOR SAND CASTING

THE composition of brass for casting varies according to the purposes for which the castings are to be used. The more zinc the alloy contains the more difficult it is to handle in the foundry. Strictly high-grade yellow brass castings will not contain more than 26% of zinc, but as such an alloy would be too soft for most of the requirements for yellow brass castings, from 1.50 to 3.00% of tin is also added, and about the same amount of lead, for without the latter, the metal would be too tough to machine properly.

A mistake too frequently made in brass-foundry practice is to put too much zinc in yellow brass mixtures for sand castings. About 30% of zinc is as high as should be attempted, unless aluminum can be added also. Considerably more zinc than this is often added to the metal in an endeavor to produce castings without loss after foolish bids have been made; but in too many cases it will be found if the situation is carefully analyzed, that the losses due to defective castings have brought the cost of the high-zinc alloy above the cost of a better casting mixture containing less zinc.

A large number of slightly differing mixtures are used in making castings of yellow brass, and these can be divided into two classes, namely, mixtures with zinc sufficiently low to permit of the production of clean castings, and secondly, mixtures with zinc so high that it would be impossible to cast them without the addition of aluminum as a flux. Owing to the fact—now well known—that the addition of aluminum permits the alloy to be highly zincked, and consequently cheapened, such alloys are regarded with suspicion by many

founders, and a non-aluminized yellow metal is demanded. A representative alloy of the first class is the following:

Standard casting yellow brass

	Pounds
Copper.....	70.00
Zinc.....	27.00
Lead.....	2.00
Tin.....	1.00

The standard casting alloy can be used wherever yellow brass castings of fair grade are demanded. It is not a strong alloy, and is merely intended for places where strength is of no great importance. It will possess the following physical properties:

Physical properties of standard casting yellow brass

Ultimate strength, lb. per sq. in.....	28,000 to 31,000
Yield point, lb. per sq. in.....	10,000 to 11,000
Elongation in 2 inches, %.....	22.0 to 28.0
Reduction of area, %.....	27.0 to 30.0
Specific gravity at 20° C.....	8.4
Brinell hardness number, 500-kg. load for 30 sec.....	50 to 55
Patternmaker's allowance for shrinkage, inch per foot.....	0.186
Weight per cubic inch, lb.....	0.30
Compression, elastic limit, lb. per sq. in.....	6,000

An alloy differing slightly from the standard yellow is that below. It is doubtful if much difference can be detected between the two. This alloy is known as a clean, running yellow brass, and the formula is:

Clean running yellow brass

	Pounds
Copper.....	69.50
Zinc.....	26.00
Lead.....	3.00
Tin.....	1.50

An alloy superior to either of the above is the following:

Fine yellow brass for ornamental castings

	Pounds
Copper.....	75.00
Zinc.....	22.00
Tin.....	2.00
Lead.....	1.00

Fine ornamental yellow is used as a dipping brass for chandelier castings, also for brass rail ornaments. In physical properties it will approach more closely to the higher figures given for standard yellow, than either of the two alloys previously given.

Brazing metal.—What is known as “brazing brass” is an alloy low in zinc and of a red color. It is a tough, ductile alloy; somewhat difficult to run in the foundry, because it has a tendency to show shrink cracks, and if not poured skillfully produces “smoky” castings. A good typical brazing metal is the following alloy:

Formula for brazing metal

	Pounds
Copper.....	86.75
Zinc.....	12.00
Lead.....	1.25

The reason for the low zinc in this alloy is to affect the melting point of the copper as slightly as possible. The alloy is most commonly used for flanges which are to be brazed onto copper pipe; the flanges having holes cast in through which bolts are inserted to join the sections of piping together. If the melting point of the flanges was too close to that of the spelter solder, they would melt or be so tender that when heated they would break. Some brazing metal contains up to 18% of zinc, but the mixture given has been thoroughly tested and will be found satisfactory. The specifications of the U. S. Government Bureau of Steam Engineering for brazing metal follow:

Composition of U. S. Government brazing metal

	Per cent
Copper.....	84.00 to 86.00
Zinc.....	14.00 to 16.00
Iron (maximum).....	0.06
Lead (maximum).....	0.30

Where the specifications permit, up to 1.5% of lead and a little lower zinc is advisable when the flanges have to be machined, as the addition of a little lead makes a great difference in the time consumed by this operation.

The specifications of the Bureau of Steam Engineering in the case of copper-zinc alloys follow:

	<i>Commercial brass</i>	<i>Cast Naval brass</i>
	Per cent	Per cent
Copper.....	64 to 68	59 to 63
Zinc.....	32 to 34	35.5 to 40.5
Iron (maximum).....	2	0.06
Lead (maximum).....	3	0.60
Tin.....	None	0.50 to 1.50

	<i>Admiralty metal</i>	<i>Screw-pipe fittings</i>
	Per cent	Per cent
Copper.....	70.00 (min.)	77 to 80
Zinc.....	29.00	13 to 19
Tin.....	1.00 (min.)	4.00
Iron.....	0.06 (max.)	0.10
Lead (maximum).....	0.075	3.00

The Society of Automobile Engineers specify the following range for yellow brass castings:

	<i>Yellow brass for automobiles</i>
	Per cent
Copper.....	62 to 65
Zinc.....	36 to 31
Lead.....	2 to 4

A number of other casting alloys of yellow brass are given in the accompanying table:

TABLE 43.—*Yellow brass mixtures for sand castings*

Suitable for	Copper, lb.	Zinc, lb.	Tin, lb.	Lead, lb.
Valves and fittings.....	75.00	20.00	2.00	3.00
Helmet metal.....	72.00	28.00		
Plumbers' brass goods.....	70.00	26.50		3.50
Gas cocks.....	65.50	30.50	2.00	2.00
“ “ (cheap).....	66.00	31.00	None	3.00
Ordinary rail fittings.....	66.00	33.00	“	1.00
Saddlery hardware.....	66.00	33.00	“	3.00
Hose couplings.....	65.00	30.00	2.00	3.00
Common yellow castings.....	64.75	32.00	None	3.25
Plumber's common yellow.....	68.00	27.00	“	5.00
Auto trimmings.....	65.00	32.00	“	3.00
Screw rod *.....	62.00	35.75	“	2.25
Naval brass *.....	62.00	37.00	1.00	None

* These mixtures are not casting alloys, but are here given as such metal is frequently found in the scrap piles, the composition being known, the mixtures can be figured accordingly.

Aluminized yellow brass.—When aluminum is added to yellow brass, the zinc content can be much higher than if the former were not added. The effect of the aluminum is to flux the brass of impurities and confer on it great fluidity. These mixtures should not be poured at a temperature sufficiently high to cause the zinc to smoke strongly; the zinc smoke should only be seen when the surface of the molten alloy is broken. Following is a formula for saddlery hardware:

Mixture for saddlery hardware

	Pounds
Copper.....	55.25
Zinc.....	41.25
Lead.....	3.00
Aluminum.....	0.50

In the above alloy the aluminum content is at a maximum, and generally it may be considered that 2 oz. of aluminum per 100 lb. of brass is sufficient to act as a flux.

Sometimes more lead than the above is added, as in the following alloy, extensively used for casting plumber's ferrules:

Ferrule mixture

	Pounds	Ounces
Copper.....	54	11
Zinc.....	40	
Lead.....	5	
Aluminum.....		5

The ferrule mixture makes 100 lb. It is a very fluid alloy, and represents the lowest cost that can be obtained with all-new metals. The alloy is strong, machines well, and is so fluid that it will run castings almost impossible to be made with any other alloy. The next two formulas are imitation manganese bronze and emerald bronze:

Imitation manganese bronze

	Pounds	Ounces
Copper.....	55	
Zinc.....	43	12
Tin.....		12
Aluminum.....		8

Emerald bronze

	Pounds	Ounces
Copper.....	50	
Zinc.....	49	11
Aluminum.....		5

Emerald bronze is a hard alloy with a beautiful golden yellow color externally. It can be finished by tumbling, and when lacquered it has been extensively used for ornamental castings.

In using aluminum in yellow brass, the more aluminum added the greater the tendency to shrink and run drossy. On the other hand, if these difficulties can be overcome in gating and pouring the molds, a brass containing 6 oz. of aluminum per 100 lb., will present a richer appearance in castings than a brass containing 1 or 2 oz. of aluminum. The aluminum content can frequently be closely approximated by the skilled observer by the shade of coloring on the castings, as when the latter have a whitish appearance, instead of a golden yellow, the aluminum is either low or the mixture is heavily leaded.

Another alloy extensively used for thin castings such as grilles is the following:

<i>Grille metal</i>		
	Pounds	Ounces
Copper.....	57	3
Zinc.....	42	8
Aluminum.....		5

Tombac.—The term “tombac” is applied to copper-zinc alloys, which, on account of their low zinc content—at the utmost 18%—have a golden-yellow, reddish, to red-brown color, instead of the yellow brass color. Articles of such an alloy having the appearance of gold are said to have been brought in the 17th century from Siam to Europe, and the Malayan name *tambaga* (actually copper) was converted into tombac. According to other definitions, the word has been formed by reversing the syllables of the Chinese *packfong* or *packtong* (white copper).

Pure tombac—that is, the alloy free from tin, lead, and other bodies impairing flexibility—is distinguished by a comparatively high degree of ductility at the ordinary temperature; but, like most all other varieties of brass, cannot be worked at higher temperatures. It is chiefly used for the manufacture of fictitious gold articles which possess a gold-

like color, and are generally made by "striking up" in a die under a press or a drop-hammer, for which purpose a very flexible and tenacious metal is required, as otherwise the articles would crack. To this class belong cheap jewelry and ornaments, buttons, and Dutch gold leaf. The varieties of tombac which contain not less than 10%, and not over 18% of zinc possess a color most closely resembling that of gold. Articles made from such alloys are generally thinly gilded as otherwise they soon turn black and require frequent cleaning.

While tombac generally contains 84 to 85 parts of copper and 15 to 16 parts of zinc, the proportions vary considerably as may be seen from the following table:

TABLE 44.—Composition of various tombacs

	Parts		
	Copper	Zinc	Lead
Cast tombac, German.....	87.00	13.00	
" English.....	86.38	13.63	
Tombac, German (Oker).....	85.00	15.00	
" " (Hegermühl).....	85.30	14.70	
" Paris (red).....	92.00	8.00	
" for gilding, German.....	97.80	2.20	
" " French.....	86.00	14.00	
" German (Lüdenscheld).....	82.30	17.70	
" French (yellow).....	80.00	17.00	3.00
" golden-yellow.....	89.97	9.98	0.05
" " ".....	82.00	17.50	0.50

Mannheim gold or similar.—This alloy has a beautiful golden-yellow color, and its composition varies considerably. Below are two prescriptions:

Formulas for Mannheim gold

	Per cent—	
Copper.....	83.7	89.8
Zinc.....	9.3	9.6
Tin.....	7.0	0.6

Chrysochalk (gold-copper).—This term is applied to several alloys resembling gold, which may consist of 95.0

parts copper, 7.9 parts zinc, 1.6 parts lead; or 58.68 parts copper, 39.42 parts zinc, and 1.90 parts lead.

The beautiful color of this alloy soon disappears on exposure to the air, but can be preserved for some time by coating articles with a colorless lacquer. Chrysochalk is generally used for ordinary gold imitations, such as watch-chains, and articles of jewelry.

Chrysorin.—This alloy, prepared by Rauscherber, consists of 66% copper and 34% zinc. Its color resembles that of common, ordinary brass, which it is.

Pinchbeck.—The alloy known under this name was first manufactured in England, and is distinguished by its dark gold color, which comes nearest to that of gold alloyed with copper. Being very ductile, pinchbeck can be rolled out into very thin plates, which can be brought into any desired shape by stamping. The alloy does not readily oxidize in the air, and is therefore well adapted for cheap articles of jewelry, for which it is principally used. Pinchbeck answering all demands is composed of 88.8 to 93.6% copper and 11.2 to 6.4% zinc; or 0.7 to 1.0 parts brass, 1.28 to 2.0 parts copper, and up to 0.7 part zinc.

French orïde.—This alloy is distinguished by its beautiful color which closely resembles that of gold. In addition to its striking color, it is very ductile and tenacious, so that it can readily be stamped and rolled; it also takes a very fine polish. The directions for preparing this alloy vary very much, some from French factories showing the following compositions:

Composition of orïde

	Per cent		
Copper.....	90.0	85.5	82.75
Zinc.....	10.0	14.5	16.40
Tin.....	.....	.....	0.55
Iron.....	.....	.....	0.30

Talmi or talmi-gold.—Cheap articles of jewelry, chains, earrings, bracelets, etc., were first brought into commerce from Paris under the name of "talmi-gold," which were distinguished by beautiful workmanship, low price, and great

durability. Later on, when this alloy had required considerable reputation, other alloys, or rather metals, were brought into commerce under the same name, which retained their beautiful gold color; only, however, as long as the articles manufactured from them were not used.

The finer quality of talmi-gold retains its pure gold color for some time, and consists actually of brass, copper, or tombac covered with a thin plate of gold combined with the base by rolling. The plates thus formed are then rolled out by passing through rolls, whereby the coating of gold not only acquires considerable density, but adheres so firmly to the base that articles manufactured from the metal can be used for years without losing their beautiful appearance. Analyses of a number of samples follow:

Analyses of talmi-gold samples

Alloy metals:							
Copper.....	89.99	90.79	90.00	{ 90.69 88.16	{ 87.48 83.13	{ 93.46 84.55	86.4
Zinc.....	9.32	8.33	8.9	{ 8.97 11.42	{ 12.44 16.97	{ 6.60 15.79	12.2
Tin.....	.....	.....	.....	.....	.....	.....	1.1
Iron.....	.....	.....	.....	.....	.....	.....	0.3
Gold.....	1.03	0.97	0.91	{ 0.05	{ 0.03	{ 0.05	

Tissier's metal.—This alloy is distinguished by great hardness, and differs from the previously described compounds by containing arsenic. It has a beautiful tombac red color. Its composition is not always the same, the quantities of the component metals varying within wide limits. The alloy actually deserving the name is composed of 97 parts copper, 2 parts zinc, and 1 to 2 parts arsenic.

According to this composition, Tissier's metal may be considered a brass containing a high percentage of copper, and hardened by an addition of arsenic. It is sometimes used for axle-bearings, but can be suitably replaced by other alloys—to be mentioned later on—which are preferable on account of lacking the arsenic, which is more or less dangerous.

Tournay's metal.—This alloy is much used by French manufacturers of bronze articles, and on account of its great ductility it can be employed advantageously in the manufacture of cheap jewelry to be made from very thin sheet. It is also well adapted for the manufacture of buttons. It is composed of 82.54% copper and 17.46% zinc.

Platina.—A white alloy, especially suitable for buttons and containing 80% brass and 20% copper.

Manilla gold.—Consists of copper and zinc, or lead.

Dutch leaf or Dutch gold.—Copper, 77.75 to 84.5%; and zinc 15.5 to 22.25%. The alloy is pale to dark yellow according to the proportions of copper and zinc used. Being very ductile, it is employed in the manufacture of Dutch leaf or Dutch gold.

Rolling and hammering.—The alloy is melted in graphite crucibles and cast in iron molds to semicircular bars about 24 inches long and $\frac{1}{2}$ or $\frac{3}{4}$ inch wide. The bars are then rolled cold, and each resulting ribbon is made into a pile about 2 feet long and beaten under the hammer to a ribbon about $1\frac{1}{2}$ inches wide. It is then annealed and beaten into a ribbon $2\frac{1}{4}$ inches wide, and, after further annealing, into one $3\frac{1}{2}$ to 4 inches wide. This last ribbon is pickled in dilute sulphuric acid, washed, boiled bright in argol (potassium bitartrate) solution, washed, brushed, and quickly dried. The ribbons are then cut up, and 1000 to 2000 pieces are made into a pile and beaten under the hammer. The material is then again cut up, the leaves are placed between parchment and reduced by beating to about $5\frac{3}{4}$ inches square. Each leaf is then cut up into 4 pieces, which are placed between goldbeater's skin, and beaten by hand to about four times the size of the original leaf. The hammer used weighs $5\frac{1}{2}$ to 11 lb., and the work is performed upon an anvil of dolomite (magnesian limestone) by alternately beating with the right and left hand, and turning the package with the free hand. The package is made up of from 800 to 1000 goldbeater's skins, between which the metal leaves are placed; on top and bottom come six parchment leaves, and the whole is then tied up in parchment.

After the heavy hammer has been used for about an hour, beating is continued for about 2 hours with a hammer weighing from 12 to 16½ lb. To prevent the leaves from adhering to the skins owing to the development of heat they are coated with gypsum (sulphate of lime). The leaves, when taken from the skins, are trimmed and placed in small books between tissue paper rubbed with rouge. Each book contains from 21 to 25 leaves.

Dutch leaf is used for gilding all sorts of articles, and its beautiful color may be preserved for some time by applying a coat of thin colorless or slightly yellow lacquer. By adding to the latter a small quantity of a pure color—aniline colors being well adapted for the purpose—the color of the leaf can be readily changed to red, green, violet, and the like.

Bronze powders.—These powders, used for coating metallic and non-metallic articles (wood, plaster of Paris, oil-cloth, wall-paper, etc.), consist of tombac-like alloys. For colors shading strongly into white, metallic mixtures with a high percentage of zinc are used; and for those approaching more closely to a pure red, alloys with a large copper content.

The many shades of color on the market, are, however, not produced by the employment of different compounds, but by heating the alloys converted into an impalpable powder until the desired shade is obtained by the formation of a thin layer of oxide on the surface of each particle. Bronze powders are now sold, showing beautiful green, blue, and violet colors, which are, however, not obtained by the formation of a layer of oxide, but by coloring the metallic powder with aniline color. The manner of preparing bronze powders has been much improved by the use of suitable machines for the conversion of the alloys into powder.

In metal-leaf factories, the waste from rolling and hammering is used for the preparation of bronze powder. By the old method, the waste was rubbed on a stone with a honey or gum solution until a mass consisting of fine powder combined to form a dough. This dough was thrown into water, and after the solution of the agglutinant, the metallic powder was

dried and subjected to oxidation by mixing it with a little fat, and heating it in a pan over an open fire until the desired shade of color was obtained. This laborious method has been much shortened by the use of suitable machines and alloys prepared by melting together the metals in suitable proportions for powders which do not require to be colored by oxidation. These alloys are beaten out into thin leaves by hammers operated by steam. The leaves are then converted into powder by forcing them through the meshes of a fine iron-wire sieve with the assistance of a scratch-brush. This rubbing through is effected with the simultaneous admission of oil, and the mass running off from the sieve is brought into a grinding machine of peculiar construction—a steel plate covered with fine, blunt-pointed needles revolving over another steel plate. In this machine, the mass is reduced to a very fine powder, mixed, however, with oil. The powder is first brought into water where the greater portion of the oil separates on the surface. The metallic mass lying on the bottom of the vessel is then subjected to a strong pressure, which removes nearly all the oil, the small quantity remaining exerting no injurious influence, rather the reverse, as it causes the powder to adhere with greater tenacity to the articles to which it is applied.

In the following table are given the compositions of the alloys for some colors:

Composition of alloys for certain colors

Color	Copper, %	Zinc, %	Iron, %
Yellow.....	82.33	16.69	0.16
Pale green.....	84.32	15.02	0.63
Lemon.....	84.50	15.30	0.07
Copper-red.....	99.90		
Orange.....	98.93	0.73	
Pale yellow.....	90.00	9.60	
Crimson.....	98.22	0.50	0.56

British bronze powders consist of 64.8 to 83.0 parts copper, 4.3 to 4.5 parts silver, 8.0 to 8.7 parts tin, and 3.0 to 4.5 parts oil; the lower grade containing 12.9 parts zinc.

The variety of bronze powder known under the name of "brocade" consists of coarser pieces prepared from the waste of metal-leaf factories by comminuting it by means of a stamping-mill, and separating the pieces of unequal size formed, first by passing through a sieve, and finally by a current of air. A certain kind of brocade, however, does not consist of a metallic alloy, but simply of mica rubbed to a fine powder. Some kinds of bronze powder, as previously mentioned, are colored with aniline colors. This is effected by simply pouring a dilute solution of the aniline color in strong alcohol over the powder, and intimately mixing.

Bronze powders from alloys of copper with 5 to 10% of aluminum and 0.04 to 1% of bismuth are, according to Lehmann, prepared directly from the block of metal by a cutting machine, heating and boiling the powder, again heating several times, rubbing, washing, drying, sifting, and polishing between rolls. Rosenhaupt used mercurous nitrate as a polishing agent for bronze powders.

Metallic powders are now directly produced electrolytically, several methods for this process having been patented in France and Germany.

Bristol brass (Prince's metal).—The alloy known by this name is simply a yellow brass of the following composition:

Formulas for Bristol brass

	Per cent—		
Copper.	75.7	67.2	60.8
Zinc....	24.3	32.8	39.2

Ronia metal.—This consists of brass with a small quantity of cobalt, manganese, and phosphorus.

D'Arcet's gilding metals.—These alloys have the following composition:

Composition of gilding metals

Copper.....	63.70	64.45	70.90	72.43
Zinc.....	33.55	32.44	24.05	22.75
Tin.....	2.50	0.25	2.00	1.87
Lead.....	0.25	2.86	3.05	2.95
Specific gravity.....	8.395	8.542	8.492	8.275

Malleable brass.—For castings which are to be shaped by forging or rolling, copper alloys rich in zinc (Muntz metal) and copper-zinc-iron alloys (Aich metal, sterro-metal, delta metal) are especially suitable, as they possess great strength and the valuable property of being ductile in the cold as well as at a red heat. From 1 to 3% of iron is claimed to increase the malleability at a red heat. It has not been decided whether the small iron content produces these properties, or whether they are due to absorption of the oxygen of the copper by the iron. A larger addition of iron impairs the ductility of the alloys. The fact that brass, which as ordinarily made is brittle at a red heat, becomes ductile at that temperature when it contains not less than 35%, and not more than 45% of zinc, appears to have first been made by J. Keir of Westbromwich, near Birmingham, England, who, in 1779, took out a patent for a mixture of 54 parts copper, 40.5 parts zinc, and 5 parts iron, which could be forged cold as well as at a red heat. This alloy was to be used for ship sheathing, and in the manufacture of nails and rivets coming in contact with sea water, etc. The matter was forgotten until in 1832 another Englishman—Muntz—took out a patent for an alloy of 60 parts copper, and 40 parts zinc, or 56 of copper, $43\frac{1}{4}$ of zinc, and $3\frac{3}{4}$ of lead, intended for the same purposes. This alloy became known as “Muntz metal” or “malleable brass.” It is still employed chiefly for ship sheathing and bolts and rivets instead of copper, because it is claimed that the sea water gradually attacks the zinc uniformly over the entire surface, and so prevents the deposit of barnacles, and similar marine growths. But according to later investigations, this brass is corroded not uniformly, but in holes.

Muntz metal sheet has been used, and is yet, instead of pure copper plate, in mills treating free gold and silver-bearing ores. The plates are scoured bright and coated with quicksilver, which catches the precious metals as an amalgam. It has been claimed that an electrolytic action is set up by the copper and zinc of the Muntz metal, plus the flow of water, crushed ore, and quicksilver, which aids amalgamation.

To the malleable varieties of brass belong the following:

Malleable brass, Muntz metal, yellow metal.—These alloys possess the valuable property of being ductile in the heat, and castings prepared from them can be worked warm like iron.

Yellow metal possesses the property of being less attacked by sea water than pure copper, and it was formerly much used for ship sheathing, and in the manufacture of nails and rivets coming in contact with sea water.

Yellow metal or Muntz metal generally consists of 60 to 62 parts copper, and 40 to 38 parts zinc.

This metal is prepared with care in order to obtain it with as uniform a grain as possible, experience having shown that only fine-grained alloys of uniform density can resist sea water. To obtain a uniform grain, small samples taken from the fused mass are cooled quickly and examined as to fracture. If the latter does not show the desired uniform grain, some zinc is added to the fused mass, and when this zinc has been intimately mixed therewith, a fresh sample is taken and tested, this being continued until the desired object is attained. It need scarcely be mentioned that considerable experience is required to tell the correct composition of the alloy from the fracture. The mass is finally poured into molds and rolled cold.

Macht's yellow metal.—This alloy, consisting of 33 parts copper and 25 parts zinc, has a dark golden-yellow color, great strength, and can be forged at a red heat, properties which make it especially suitable for fine castings.

Bobierre's metal.—This consists of 66 parts copper and 34 parts zinc, and is claimed to be especially suitable for ship sheathing.

From tests it has been learned that all alloys containing up to 58.33% of copper and 41.67% of zinc are malleable. There is, however, a second group of such alloys with 61.54% of copper and 38.46% of zinc, which are also malleable in the heat. The preparation of these alloys requires considerable experience. They are best effected by melting the metals together in the ordinary manner, and heating the fused mass

as strongly as possible; but it must be covered with a layer of charcoal dust to prevent oxidation of the zinc. By the mass becoming thinly-fluid, an intimate mixture of the constituent parts is effected. Small pieces of the same alloy previously prepared are then thrown into the liquid mass until it no longer shows a reflecting surface, when it is cast into ingots in iron molds. While still red hot the ingots are thrown into water, acquiring by this treatment the highest degree of ductility. The alloy properly prepared must show a fibrous fracture and have a reddish-yellow color.

Aich's metal.—This alloy, named after its inventor, consists of a brass to which a considerable degree of tenacity has been imparted by an addition of iron. It is especially adapted for purposes where the use of a hard, and, at the same time, strong metal is required.

According to analyses of various kinds of this metal, it shows, like other alloys, considerable variations in the quantity of the metals used in its preparation. Even the iron content, to which the hardening effect is ascribed, may vary within wide limits without the strength, which is the principal property of this alloy, being modified to a considerable extent.

The best alloy which can be called an Aich's metal is composed of 60 parts copper, 38.2 parts zinc, and 1.8 parts iron. The iron content must be limited to from 0.4 to 3.0%. Another Aich's metal showing excellent properties is composed of 60.2 parts copper, 38.2 parts zinc, and 1.6 parts iron.

The hardness of Aich's metal is claimed to be not inferior to that of certain kinds of steel. It has a beautiful golden-yellow color, and is said to oxidize with difficulty, which makes it of great value for articles exposed to the action of air and water.

Sterro-metal.—The properties of this alloy approach closely those of Aich's metal. It consists of an alloy of copper, zinc, and iron, but contains a larger quantity of iron. The composition of the alloy may vary considerably, a little tin being added sometimes. Analyses of two varieties of sterro-metal of excellent quality are as follows:

Austrian—55.33 parts copper, 41.80 parts zinc, and 4.66 parts iron; and British—60.0 parts copper, 38.125 parts zinc, and 1.5 parts iron.

The principal value of this alloy is its great strength, in which it is not surpassed by the best steel. While a wrought-iron pipe broke with a pressure of 3905 lb. per sq. in., a similar pipe of sterro-metal stood the enormous pressure of 11,216 lb. without cracking. It also possesses a high degree of elasticity, and on account of these properties is especially adapted for cylinders of hydraulic presses. As is well known, these cylinders begin to sweat at a certain pressure—that is, the pressure in the interior is so great that the water permeates through the pores of the steel. With a cylinder of sterro-metal, the pressure can be considerably increased without the exterior of the cylinder showing any moisture.

According to the purpose for which it is to be used, the sterro-metal can be made especially hard and dense, but this change in its properties is less effected by altering the chemical composition than by mechanical manipulation.

If cast sterro-metal be rolled or hammered in the heat, it acquires, besides strength, an exceedingly high degree of toughness. In hammering the metal, special care must be taken not to overheat it, as it easily becomes brittle, and cracks under the hammer.

A sterro-metal containing 55.04% copper, 42.36% zinc, 0.83% tin, and 1.77% iron was tested by de Rosthorn, of Vienna, and gave the following results:*

Strength of sterro-metal

Material	Tenacity	
	Lb. per sq. in.	Kg. per sq. cm.
Sterro-metal cast.....	60,480	4252
“ forged.....	76,160	5354
“ cold drawn.....	83,120	5984
Gun-bronze cast.....	40,320	2834

* Holley. “Ordinance and Armor.”

The specific gravity of this metal was 8.37 to 8.40 when forged or wire-drawn. It has great elasticity, stretching 0.0017 without set, and costs 30 to 40% less than gun bronze. It has been forged into guns cold from the casting.

Delta metal.—This alloy was introduced in 1883 by Alexander Dick, and on account of its strength and power of resisting the action of chemical influences it is much used in the construction of machinery as a substitute for the more expensive bronze. The name “delta” was given to it by him, simply for the purpose of connecting it with his own name, *delta* being the Greek for the letter D, the initial of his surname.

Delta metal is a somewhat ferriferous brass with a fixed zinc content—40 to 43%. It is malleable at a red heat and distinguished by its strength. To prevent oxidation during re-melting, and to keep the composition uniform, a small percentage of phosphor-copper, or, still better, manganese copper, is added. That iron is capable of increasing the strength of brass has been referred to in discussing similar alloys, but in using such alloys containing iron many failures result because the iron alloys only with difficulty, and not always uniformly, with the other two metals. In making delta metal, this drawback is overcome by first preparing an iron-zinc alloy with 8.5% of iron, by dissolving the iron in melted zinc heated to a red heat, and combining this alloy with the other metals. Besides iron, some manufacturers add small quantities of tin and lead; in some samples the presence of nickel has also been established. Analyses of articles of delta metal showed the following composition:

Composition of Delta metals (per cent)

Copper.....	55.94	55.80	55.82	54.22	58.65
Zinc.....	41.61	40.07	41.41	42.25	38.95
Lead.....	0.72	1.82	0.76	1.10	0.67
Iron.....	0.87	1.28	0.86	0.99	1.62
Manganese.....	0.81	0.96	1.38	1.09	
Nickel.....	Trace	Trace	0.06	0.16	0.11
Phosphorus.....	0.113	0.011	Trace	0.02	

The first is cast delta metal; the second, wrought; the third, rolled; and the fourth, hot stamped.

The advantages claimed for delta metal are great strength and toughness. It produces sound castings of close grain. It can be rolled and forged hot, and can stand a certain amount of drawing and hammering when cold. It takes a high polish, and when exposed to the atmosphere tarnishes less than brass.

When cast in sand, delta metal has a tensile strength of about 45,000 lb. per sq. in., and about 10% elongation; and when rolled, a tensile strength of 60,000 to 75,000 lb., and elongation from 9 to 17% on bars 1.128 inch in diameter and 1 inch area.*

Wallace † gives the ultimate tensile strength as 33,600 to 51,520 lb., with from 10 to 20% elongation.

Durana metal.—This alloy resembles delta metal, but is somewhat richer in copper, and frequently contains tin, as well as antimony and aluminum. Five analyses gave a mean composition as follows: ‡ 64.78% copper, 29.50% zinc, 1.71% iron, 1.70% aluminum, and 2.22% tin.

Like delta metal the alloy can be worked at a red heat, and is distinguished by its strength.

Tobin bronze.—This alloy is the invention of John A. Tobin, of the U. S. Engineering Corps, and was first made about 1876.

According to the inventor's claim, it can be forged and stamped at a red heat as readily as steel. Bolts and nuts can be forged from it by hand or machinery, when cold drawn. Its increased density and high elastic limit, and the facility with which it can be upset, while hot, make it well adapted for special purposes. In forging Tobin bronze it is stated that particular care must be taken to work it only at a cherry-red heat, and that it should not be worked at a black heat. Three samples contained the following:

* *Iron* (London) vol. 21, page 159.

† *Trans. of the Institution of Naval Architects*, 1888, page 374.

‡ *Zeitschrift für angewandte Chemie*, 1894.

Analyses of Tobin bronze

Metals	(1)	(2)	(3)
Copper.....	58.22	57.50	60.35
Zinc.....	39.48	40.00	38.85
Lead.....	.....	0.5	.....
Tin.....	2.30	1.50	0.79
Iron.....	.....	0.5	.....
Aluminum.....	.....	.....	0.01

No 1 contains too much tin. No. 2, with the addition of a little aluminum, would cast in sand, and produce a good metal. No. 3 is an analysis of rolled shafting, and carries sufficient aluminum to enable sand castings to be made, although the castings will not show the aluminum as they do in the case of manganese bronze. For a Tobin bronze this is not desirable. Test bars made by the author were cast in sand molds and had the following properties:

Physical properties of Tobin bronze

	No. 1 bars	No. 2 bars
Tensile strength, lb. per sq. in.	52,200	52,800
Yield point, lb. per sq. in.....	18,700	17,250
Elongation, % in 2 inches....	31.0	40.00
Reduction of area, %.....	32.3	41.20

When this alloy is called for in the course of brass-foundry operations make it as follows: First run out a small heat of an alloy of 89.50% copper and 0.5% of 30% manganese-copper. Then melt the two together, and when molten add 10% of ingot tin. Also have on hand a small quantity of 10% aluminum bronze. Make the Tobin bronze as follows:

Tobin bronze for castings

	Pounds
Copper.....	49
90-10 copper-tin alloy.....	10
10% aluminum bronze.....	1
Zinc.....	40
Total.....	100

In the tests given for Tobin bronze, No. 1 bars were cast in the form of straight round bars, $\frac{7}{8}$ -inch in diameter, and No. 2 bars were $1\frac{1}{2}$ inches round. Both types of bars were machined to standard size, and both were molded properly to ensure perfect feeding, as is necessary with such alloys.

CHAPTER XVI

MANGANESE BRONZE AND WHITE BRASS

Historical.—As it exists to-day manganese bronze is the invention of Percival Moses Parsons of London, England, who took out British patent No. 482, on February 7, 1876, and thus its age is the same as the very similar alloy, Tobin bronze, brought out in the United States. The patent issued to Parsons covered an alloy of copper, tin or zinc, or both, which was to be improved by the addition of ferro-manganese, spiegeleisen, or other “carburet of iron containing manganese.” An alloy was specified containing 90% copper, 10% tin, with from 0.5 to 1.5% of ferro-manganese containing 20% of manganese. It will be noted that Parsons added iron with the manganese, and while this is of value in the case of copper-zinc alloys, it is very detrimental in copper-tin alloys because it will segregate with manganese and carbon, and probably some tin, in the form of nodules which are intensely hard. The main object of the patent was to introduce manganese, not iron; but the only supply of manganese then available for use in non-ferrous alloys were the alloys with iron used in steel making.

In spite of the difficulties due to the iron, this form of manganese bronze—the copper-tin-manganese alloy—was extensively used for castings for ship propellers and other parts; and this was the alloy known at first as manganese bronze—it really was a bronze, not a brass—and when the formula was changed, the name continued to apply, although the alloy was no longer a bronze. The formula was changed in about 1888, as by that time Parsons had reached the conclusion that the ferro-manganese was better adapted to the copper-zinc series of alloys, and at the same time, aluminum was introduced,

which immediately made the alloy practical from a sand-casting standpoint.

A patent was taken out in Great Britain for an alloy of copper and tin or zinc; or copper and tin and zinc together; to which was added a small amount of iron or steel and manganese, also aluminum. Parsons had also previously taken out a patent in the United States, and one of the earliest makers of manganese bronze in this country was Wm. Cramp & Sons Ship & Engine Building Co., Philadelphia, Pennsylvania, who for a number of years imported the "steel alloy," as the "hardener" used in making the bronze is termed, from the original makers in England. For a long time practically a monopoly was enjoyed in making this alloy. It became known, of course, that the bronze consisted of certain proportions of copper and zinc, as this could have easily been ascertained by analysis; it was also common knowledge that ferro-manganese was used in the alloy, but the proper method of introducing it was not known, with the result that many unsuccessful attempts were made to duplicate the alloy, using the ferro-manganese. One such alloy became known as "steel bronze," and found extensive application for casting the sprocket-wheels of bicycles, then in their height of popularity. In December, 1905, however, full particulars regarding the making of the alloy, were published by Erwin S. Sperry in the *Brass World*, then just started, and the method there outlined is followed faithfully in the majority of brass foundries using the alloy to the present time.

This method, however, is far from perfect, as it is difficult to get the iron into solution in the copper, when using the steel alloy; and unless it is in solution, the alloy is merely a common, aluminized, yellow brass. It has happened many times—even with experienced makers—that sandwiched in with the good heats of metal, would be heats which caused loss and annoyance owing to poor physical properties, as the fact of their being defective is not easy to determine before they are used to make castings and a test has been made. Another defect of this method is that it is lacking in

flexibility, as it is not possible to vary the proportions of iron, manganese, and aluminum with the ease that would enable alloys of varying tensile strength and elongation to be made to meet modern requirements.

Lead in manganese bronze.—For many years after manganese bronze became well known, some rather peculiar ideas prevailed regarding the several constituents of the alloy. Thus it was thought that lead was especially harmful, and specifications for manganese bronze placed this impurity ridiculously low. It is now known that good manganese bronze can be made, when the spelter contains up to 1.5% of lead. It is also known that a high lead content in the spelter can be offset by a higher aluminum content in the alloy; the two elements can be balanced one against the other to secure the physical properties desired. Thus, commercial brands of zinc are now being used to produce manganese bronze of higher physical properties than could be obtained in the early days of the alloy by the use of zinc of the highest grade.

Manganese and iron.—Another peculiar idea was to the effect that manganese “carried” the iron. This probably arose from the fact of the association of the two metals in the then available sources of the same. That manganese does not aid the solubility of iron in copper is susceptible of abundant proof by making alloys of manganese and copper by the use of 80% ferro-manganese. If the metal is cast into sand-molded ingots in order to cool slowly, giving time for the iron to collect, it can be pulled off the molten surface of the ingots in flat cakes. With patience, probably all of the iron could be thus eliminated; but if there is any left it will be found in the castings in the shape of intensely hard nodules, which ruin any tool or file used.

Effect of carbon.—The reason why manganese does not assist in the solubility of iron in copper is to be found in the fact that both of these elements combine with carbon, while carbon is soluble only to a very limited extent in copper. Copper, therefore, does not seek to form carbides, it has no

power to break up the carbides of other metals; hence, when metallic carbides are added to molten copper, no union can take place unless the affinity of the metal united to the carbon is greater for copper than for carbon. This is not so in the case of iron, therefore, in order to alloy iron with copper, the carbon must be eliminated.

Cast iron in copper.—This is also susceptible of proof. When cast iron and copper are melted together, no matter how much they are mixed mechanically, they will separate on solidification.

Influence of aluminum.—If aluminum is added to the molten mixture of cast iron and copper, having greater affinity for the two metals than for carbon, it immediately combines with both of them, forming an alloy of copper, iron, and aluminum, while the carbon is thrown out of solution and rises to the surface of the bath as flocculent graphite.

Manganese, however, would unite with the iron and its carbon; it would not form an alloy as the aluminum did. Aluminum is a carrier of iron, and in the case of aluminum bronze there is no difficulty in getting a considerable amount of iron alloyed therewith.

The steel alloy used in the manufacture of manganese bronze was given by Sperry as follows:

<i>Steel alloy for making manganese bronze</i>		Pounds
Wrought iron.....		12
Ferro-manganese.....		4
Tin.....		10
		<hr/> 32

The iron and ferro-manganese were melted together, a feat that taxed the melting capacity of most brass furnaces. Solid fuel (charcoal) was to be used as a covering, and when the iron was liquid the tin was added, and the whole ingoted or shotted. It is better to pour it into thin flat cakes, for many serious accidents have happened while shotting this alloy, owing to foundrymen being unfamiliar with the shotting of metals.

Parsons' manganese bronze.—The bronze is made as follows:

Formula for manganese bronze

	Pounds
Copper.....	56.00
High-grade zinc.....	43.00
Steel alloy.....	2.00
Aluminum.....	0.50
	<hr/>
	101.50

The 1.5% zinc over the total 100% is to allow for loss of zinc due to volatilization. Sixteen years later the same formula was being used by a large manufacturer of manganese bronze castings and ingot. Figured in percentages, the steel alloy is as follows:

Steel alloy for manganese bronze

	Per cent
Wrought iron.....	56.25
Tin.....	31.25
Ferro-manganese.....	12.50

Compare this steel alloy with the original Rich alloy imported from England as follows:

	<i>Imported Rich alloy</i>	<i>Steel alloy</i>
	Per cent	Per cent
Iron.....	62.00	58.75
Manganese.....	6.00	10.00
Tin.....	32.00	31.25

The difference between the Rich alloy and the steel alloy is principally in the manganese content. An analysis, however, would not show much, if any, difference on account of the loss of manganese in making the alloy. The difficulty to be expected when making such refractory metals in a brass-melting furnace is carbonization, for, if the manganese and iron are saturated with carbon, they will not alloy with copper, but will be thrown out as dross, consequently the finished bronze does not contain the strengthening elements it is expected to contain, and failure to meet specifications is inevitable.

To show what happens, and to point out a moral in connection with the making of this steel alloy, an analysis of an alloy made in a brass furnace, presumably by experienced operators, will be given, as follows:

Analysis of steel alloy

	Per cent
Iron.....	72.05
Manganese.....	3.78
Tin.....	15.56
Carbon.....	5.91
	<hr/> 97.30

The formula charged was as given for steel alloy, and the change was due to burning out the tin and carbonizing the iron and manganese, with the result that the bronze made with this alloy was filled with lemon-colored spots and was worthless. When difficulty is experienced, therefore, in making manganese bronze with this formula, it will be advisable to investigate this possible source. The bronze should give approximately the following analysis:

Analysis of manganese bronze

	Per cent
Copper.....	56.00
Zinc.....	41.50
Iron.....	1.20
Tin.....	0.70
Manganese.....	0.10
Aluminum.....	0.46

Manganese bronze made to the above analysis will have the following physical properties:

Physical properties of manganese bronze

Ultimate tensile strength, lb. per sq. in.....	70,000
Yield point, lb. per sq. in.....	33,000
Elongation in 2 inches, %.....	22 to 35
Reduction of area, %.....	25
Specific gravity at 20° C.....	8.4
Brinell hardness number, 500-kg. load for 30 sec.....	104 to 119
Patternmaker's allowance for shrinkage, inch per foot.....	0.25
Weight per cubic inch, lb.....	0.30
Compression, elastic limit, lb. per sq. in.....	28,000

Use of manganese bronze.—Manganese bronze is a strong alloy, but it is not a bearing alloy; it is suitable where very strong castings are required: When manganese bronze was first introduced, its competitor was aluminum bronze (the ordinary 10% aluminum alloy), and the former, being cheaper and easier to cast, became more popular. The introduction of the aluminum-iron-copper alloys, however, prove that

aluminum bronze is the better alloy (see aluminum bronze). The formulas given in the above are for Parsons' manganese bronze, but there are a number of different formulas, of which the following are examples:

Manganese bronze (formula 2)

	Pounds equals	Per cent
Copper.....	52.00	56.20
Zinc.....	46.00	46.00
Iron.....	1.00	1.00
Tin.....	1.00	1.00
Manganese copper (30% Mn).....	6.00	1.80 Mn
Aluminum.....	0.25	0.25

This alloy was tested by the author with the following results:

Properties of manganese bronze (formula 2)

	(1)	(2)	(3)
Tensile strength, lb. per sq. in.....	71,800	70,800	72,300
Elastic limit, % in 2 inches.....	32,900	30,800	30,700
Elongation, % in 2 inches.....	36.5	26.5	32.5
Reduction of area, %.....	33.7	25.7	30.7

Manganese bronze (formula 3)

	Pounds
Copper.....	56.00
Zinc.....	42.00
Iron.....	1.50
Tin.....	1.00
Aluminum.....	0.50
80% Ferro-manganese.....	0.50

The alloy was ingoted, and the ingots were re-melted to make the tests as follows:

Properties of manganese bronze (formula 3)

Tensile strength, lb. per sq. in.....	83,300
Elastic limit, % in 2 inches.....	42,800
Elongation, % in 2 inches.....	21.3
Reduction of area, %.....	22.1

Manganese bronze (formula 4)

	Pounds
Copper.....	44.00
Best zinc.....	42.00
30% Manganese copper.....	12.00
Aluminum.....	2.00

Properties of manganese bronze (formula 4)

	1st test	2nd test
Tensile strength, lb. per sq. in.	92,400	91,900
Elastic limit, % in 2 inches.	42,800	46,100
Elongation, %	21.5	21.5
Reduction of area, %	20.8	20.4

The specifications of the U. S. Navy Department for manganese bronze are as follows (minimum and maximum): 55 to 60 parts copper, 42 parts zinc, none to 1.5 parts tin, none to 3.5 parts manganese, none to 1.5 parts aluminum, none to 2.0 parts iron, and 0.03 to 0.2 parts lead. The sum of the specified elements shall equal 99.8%. This specification gives sufficient leeway, in the case of all metals, with the possible exception of aluminum. Some alloys might contain 2% of aluminum as shown in the previous formulas. Very strong alloys will contain as high as 3.5% of aluminum, therefore the specification for this element should be raised to 3.5%.

Manganese content in bronze.—As some manganese bronzes contain no manganese upon analysis, and others contain, say about 0.5% of this element, any alloy that contains an appreciable amount of manganese is entitled to the term manganese bronze. An alloy of 90% copper, and 10% tin, with 0.5% of the copper replaced with an equal amount of manganese copper, is as much a manganese bronze as the alloys of copper and zinc to which the name has been applied; all that is necessary is to meet the requirements for tensile strength and elongation.

The specifications of the American Society for Testing Materials are 55 to 60% copper, 39 to 45% zinc, 2% tin, 2% iron, 0.5% aluminum, 0.5% manganese, and no lead.

In these specifications the aluminum is too low, so is the manganese. While a few manufacturers may limit these two elements to the amounts specified, others might desire to run them higher. Neither aluminum nor manganese are harmful; in fact, they are important constituents of the alloy, and it

might be discovered that high aluminum and manganese, with lower zinc, would avoid the troubles that were encountered with the manganese bronze used by the Board of Water Supply of New York City.

Failures of manganese bronze.—All of the bronze used for the Catskill Viaduct would conform to the above specifications, and its record is not pointed to with pride. If the manganese, aluminum, and the iron are limited to low percentages, the alloy is merely a yellow brass; perhaps a little strengthened, but still a yellow brass, with all the failings of that alloy. An example of where a yellow brass should not be used is found in the splicers that hold electric railroad trolley wires. In one case, where a yellow brass containing sufficient silicon to make it run like a manganese bronze was used, not the least difficulty was encountered in bending the metal over the wire. It was very ductile, but in the course of a few weeks it had so crystallized that long stretches of the wire fell to the ground. In such situations a red brass is indicated, not a manganese bronze.

Other copper-zinc alloys.—Three other alloys have the following composition by analysis:

Analysis of other bronzes

	Tensilite	Titan bronze	Turbadium bronze
Copper.....	64.00	55.93	48.00
Zinc.....	29.13	43.53	46.45
Iron.....	1.14	0.26	1.00
Tin.....	0.16	Trace	0.50
Lead.....	0.07	.....	0.10
Manganese.....	2.45	.....	1.75
Aluminum.....	3.13	0.21	2.00
Silicon.....	Trace	.....	.....
Nickel.....	.....	.....	2.00

Turbadium bronze is supposed not to corrode in salt water. Tensilite is an improved manganese bronze, and its composition varies. The following properties were found for tensilite of the foregoing analysis, using test bars made

from castings obtained from the American Manganese Bronze Co., makers of the alloy:

Physical properties of tensilite

Ultimate strength, lb. per sq. in.	98,000
Elastic limit, lb. per sq. in.	30,700
Elongation, % in 2 inches.	16.0
Reduction of area, %.....	16.9

The above bars were taken from an ordinary casting. The original metal would possess higher tensile, and the company's claim for tensile, namely, 105,000 lb., is within reason.

An analysis of Stone bronze, as charged, is as under:

Analysis of Stone bronze

	Per cent
Copper.....	58.00
Zinc.....	39.00
Iron.....	1.50
Manganese.....	0.50
Tin.....	0.25
Aluminum.....	0.75
	<hr/> 100.00

Making manganese bronze.—This alloy can be made in crucible furnaces, either tilting or “tap-out” oil or gas-fired furnaces, also in electric furnaces. The difficulty encountered in the case of furnaces that melt in bulk and tap out is that the metal may burn on the surface and be cool—barely melted—below, and same method must be adopted to bring up the cool metal from underneath, and continually stir the metal, otherwise, if this is neglected, the surface bronze will burn, and the composition of the entire melt will be altered. This difficulty can be overcome, however, by the exercise of a little ingenuity. Manganese bronze can also be made in a cupola; in which case the composition of the steel alloy is somewhat different to the formulas previously given. The following formula is used by some firms:

Steel alloy for cupola

	Per cent
Steel punchings.....	42.00
80% ferro-manganese.....	40.00
Tin.....	18.00

Usually the steel alloy is made in an electric furnace of the arc type, in large heats. The mixture for the bronze is as follows:

Cupola manganese bronze

	Pounds
Copper.....	57
Zinc.....	41
Steel alloy.....	3
Aluminum, ounces.....	3

The steel alloy is mixed in with the copper, the two being melted together in the cupola, the blast being about the same as that used for iron. The copper and the steel alloy are brought down quickly and tapped into heated ladles, then the zinc and aluminum are added, and the mixture is completed by pouring back and forth—4 to 6 times—from ladle to ladle. In this way propellers are cast from cupola-melted manganese bronze.

To make manganese bronze, a fair grade of virgin copper and zinc is all that is required. Lead in the zinc, up to 1.5%, and cadmium up to 0.5%, are not harmful, and manganese bronze is being run into ship propellers using such material, every day. Scrap metals may also be used, but to ensure against excessive lead it is better to use rolled scrap yellow brass of known composition. The greatest enemy of manganese bronze is antimony; next to which tin might be listed. For this reason re-run spelter is not advisable in making this alloy; also re-run copper. The chief difficulty is to get the iron and manganese into solution with the copper, and to do this properly they should be in the form of an alloy containing no carbon.

A typical charge of metal to make manganese bronze in a reverberatory furnace is given by P. E. McKinney, chemist and metallurgist at the Naval Gun Factory, Washington, D. C., in a paper* presented before the American Institute of Mining and Metallurgical Engineers, as follows:

* Transactions American Institute of Mining and Metallurgical Engineers, vol. LX, 1919, p. 376.

Reverberatory charge for manganese bronze

	Pounds
Yellow-brass machine-shop turnings.....	1250
Zinc dross from galvanizing plant.....	400
Aluminum turnings.....	30
Recovered scrap zinc.....	400
Dross-skimmings from billet and slab plant.....	2000
Foundry floor scrap and skimmings.....	650
Hardener, made by melting equal parts of scrap copper and manganese.	250
Charcoal.....	75
Common salt.....	80

In charging the furnace, the manganese hardener is placed in the bottom, and on top the cartridge-case dross and the zinc dross with a layer of charcoal; then the foundry skimmings and turnings are added, and the charge is melted and rabbled. When all is melted, the aluminum scrap is added, then the necessary zinc additions, after which the melt is allowed to cool slightly, and is poured into ingots. These are analyzed, and can be brought up to proper formula when re-melted for casting purposes. The average tensile is 69,000 lb. with 25% average elongation.

The pouring temperatures for manganese bronze are given by Gillett as between 1900 and 2000° F. for heavy castings, and a little hotter for test bars. The temperatures for pouring large castings at the Philadelphia Navy Yard are given as 1790 to 1810° F.

Manganese-bronze propellers.—The physical properties of the bronze used for propellers is not the same for all types, some may require a very stiff metal, others a very ductile metal. Thus high-speed, turbine-driven propellers have wide blades with thin edges, and a very ductile metal would not retain its shape; a stiff metal is therefore used in such a case, such as tensilite or turbadium bronze, analyses of which have been given. But where such a bronze is desired, it would be advisable to purchase the ingots from the original makers of the alloy, and thus benefit by their accumulated experience in making them.

Low-speed reciprocating marine engines are usually fitted with propellers of ductile manganese bronze, so that the blades may be straightened if bent through contact with rocks, etc.

The blades of propellers may be cast separately, or the entire propeller may be cast as an entity, such castings frequently weighing 30 tons each. Single blades are often cast on end, and the bronze may be made in crucibles, oil-fired furnaces—either tap-out or tilting—or in electric furnaces. The Oregon Brass Works, at Portland, Oregon, has two Detroit electric rocking furnaces (figure 31), one of 2000-lb. and one of 1000-lb. capacity. The large furnace is operated entirely on manganese bronze. Oil-fired tap-out furnaces are also used, and for a 6000-lb. heat for a propeller blade, 3000 lb. of bronze will be melted in the electric furnace (50% overload) and 3000 lb. is melted in the low-pressure, tap-out oil-fired furnace, and the two heats are mixed. The metal is first pigged, and the pigs are re-melted for the castings to maintain the reputation that has been established for high-grade work. The shrinkage on the first melt is kept down to $2\frac{1}{2}\%$ and that on the second melt to $7\frac{1}{2}\%$, in order to get a minimum elongation of 26%. In a run of 42 propeller blades recently cast, the average tensile strength was 68,000 lb., and average elongation 26.8%. The bronze was made by the "Vickers' method," the physical properties of the metal being gaged to meet the specifications satisfactorily, and also economize on metal costs. A tensile of 90,000 lb. with 25% elongation could be obtained by this method, but the metal cost is increased; therefore it is an economy when specifying a grade of manganese bronze to meet certain requirements to choose that which will be certain to meet them, but will not surpass the same in any extraordinary manner.

In some cases a demand is made for 60,000 lb. tensile and 20% elongation, and others 68,000 lb. and 22% as in the case of the propellers mentioned; others may require 70,000 lb. with 20% or over elongation. For broad-bladed, thin propellers the tensile should be consistently in the 80,000-lb. class. Turbadium bronze runs from 78,000 to 94,000 lb., with 14%, or a little better, elongation. Cupola-made manganese-bronze propeller blades will possess approximately 60,000 lb. tensile, with from 18 to 22% elongation. Such

castings cannot help but be greatly inferior to brass-furnace melted, re-run manganese bronze; and it doubtful whether in such a case cheapness pays in the long run.

Manganese-bronze test bars.—The test bars from which the strength of an alloy of manganese bronze is to be determined must be sound and free of segregation. This is true, of course, of all metals and alloys, but the same methods of obtaining soundness of test bars do not produce good results for all alloys. Thus, in the case of alloys of copper and aluminum (aluminum bronze), or alloys of aluminum known as the light alloys, a test bar representative of their strength could be made by molding a $\frac{3}{4}$ -inch straight round bar, about 8 inches long, and feeding it solid by placing a riser 2 inches in diameter on each end. But such a bar in manganese bronze would most likely have a core of metal of a lemon color running through it in the direction of its length, and tapering to a point towards each riser, like a sharpened peg. Such a bar would pull all of 10,000 lb. under the actual strength of the metal, and its elongation would also fall off greatly.

Manganese bronze and gun-metals, comprising all copper-tin and copper-zinc alloys, require very similar treatment in casting bars so as to get them sound; but manganese-bronze test bars require feeding in greater degree to ensure soundness, and of course this also applies to the castings.

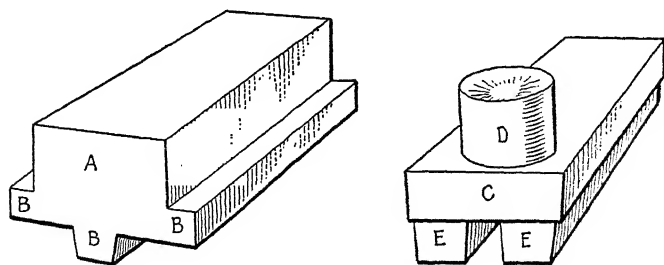


Figure 70.—A method of obtaining specimens of manganese bronze.

A method of making manganese-bronze test bars is shown in figure 70. The block *A* at the left is the usual manner in

which test bars are made, and it is cast as shown with the stepped out part downwards. The part *A* is supposed to be necessary to feed the parts *B*, which are the test coupons. These have to be cut off the main body and machined to the proper shape and dimensions for a standard test bar, which, in the case of the finished specimen is, length of center section, 2 inches between gage points; and diameter of center section, 0.505 inch. The length of the bar may vary according to the manner in which it is to be gripped by the machine; thus, when the grips are threaded, the length of the bar will be 4.5 inches; length of each threaded grip, 1 inch; and diameter of the threaded ends or grips, $\frac{3}{4}$ inch. Some foundries prefer to make the finished test bar 4.75 inches long; the center portion is turned to $\frac{1}{2}$ inch diameter, and perfectly straight for a length of 2 inches. This center curves to the larger diameter of the grips, this curve being on a radius of $\frac{5}{8}$ inch, forming what is known as the "fillet." When the bar is tested it is threaded into holders on the tensile machine.

In another type of test bar, the dimensions of the portion on which the strain is measured is the same as above given but the ends or grips are only about $\frac{1}{2}$ inch long, as the testing machine is fitted to seize the bar just under each filleted end. Then there are operators who insist on having grips on the test bars that are straight and round and $\frac{3}{4}$ inch diameter by $2\frac{1}{2}$ inches long each, which are seized by chucks attached to the testing machine.

While in the case of many alloys an unnecessarily long test bar may not matter much, in the case of aluminum bronze, aluminum alloys, and manganese bronze, it is harmful and inexcusable. The first two of these three should be fed sound from the ends of the grips, for reasons set forth in the chapters dealing with those alloys; and the longer the grips are made the less likely will be the risers to ensure soundness at the center of the bar where the pulling strain will come. In the case of manganese bronze, where test bars are made as in figure 70, an unduly long test bar means that a much greater mass of metal must be melted and machined to get the same

results as with the smaller test bars. In general, test bars should be made as short as possible, consistent with getting the proper results from them.

The manganese-bronze test bar shown in figure 70 was devised by Paul S. Reeves & Son of Philadelphia, but in its original form it carried only the two side coupons. The bottom one, which gives to that type of test casting its name of "keel block," was suggested as an addition by G. H. Clamer of the Ajax Metal Co. of Philadelphia. The block *C* requires considerably less molten metal to pour it than the keel block, and gives practically the same results. The keel block is also made with a heavy riser *D* on one end. Both of these blocks are cast on an incline, the mold being elevated at one end, and the sprue and riser are at the high end; but the sprue communicates with a long runner which carries the metal to the lower end of the mold cavity, where, entering, it has to flow up-hill to fill the casting, the riser being filled last.

With such heavy masses of metal required for test bars, and the machine work required to cut them off the blocks and turn them to finished size, making test bars of manganese bronze is an expensive matter, hence, such tests are avoided whenever possible. A much more economical method of making such test bars is the one devised by the author, and shown on figure 71. This illustration shows what are termed "cast-to-size" test bars. In practice, however, it has been found an improvement to make the bars straight rounds—that is, not turned off at the center to shape as shown. A straight round bar about 5 inches long and $\frac{13}{16}$ inch diameter can be easily and quickly finished in the lathe into a perfect standard test bar; and when done is something to be proud of; whereas a cast-to-size bar is frequently a little off round or contains little flaws, which may cause doubts to arise as to the correctness of the results obtained—and doubtful tests are valueless.

In figure 71 it will be noted there is a "feeder" of comparatively heavy section laid parallel with the test bar in the cope of the mold. This feeder does not cut through the

cope, and it is connected to the test bar by an opening which extends its entire length as shown; and it is very important that the opening from test bar to feeder be made to thicken sharply towards the feeder. The width of the opening where it attaches to the test bar should be $\frac{5}{16}$ inch, and the feeder itself should be about three times as heavy as the test bar. The metal is not poured through the feeder into the test bars, as in the Weber fin-gate test-bar method. This is likely to run a dirty bar. The metal runs from the sprue down the runner, and is distributed by the gates to the two bars, and enters the castings at the ends of the grips. The mold is

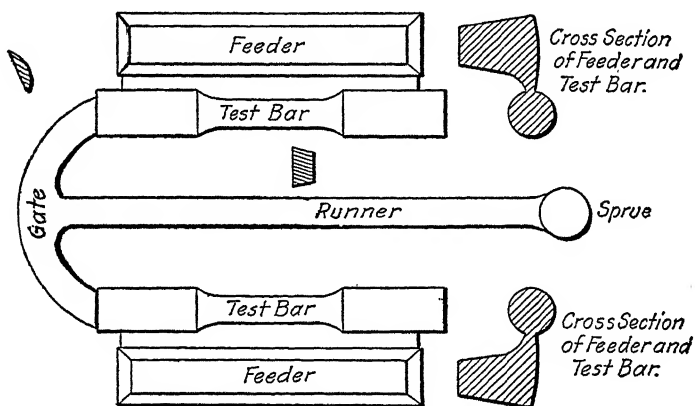


Figure 71.—Fin-feeder method for test-bars (Vickers).

poured flat, and the molten metal fills half of the test bar; then enters the feeder through the long gate, which checks the flow of the metal. Then it rises gently in both bar and feeder, finally flowing all of the metal out of the bar, several times and into the feeder, ensuring freedom from sand and dross particles in the bar. The bar being so much smaller than the feeder solidifies first, and when this is taking place metal is continually being drawn by gravity from the molten reservoir in the feeder. This ensures clean and sound test bars, and this method can be used for manganese bronze, gun-metals, composition alloys (such as steam metals and red brass), and also for yellow brass. The patterns with gates and feeders

can be put on plates, or be gated, so that the cost of molding is reduced to a minimum. Many of the tests given in this volume by the author, with the exception of aluminum bronze and aluminum alloys, were made from test bars so molded and gated.

Structure of manganese bronze.—The microphotographs (figures 72, 73, 74, and 75), show the structure of manganese bronze. Figure 72 is a manganese bronze to which an addi-

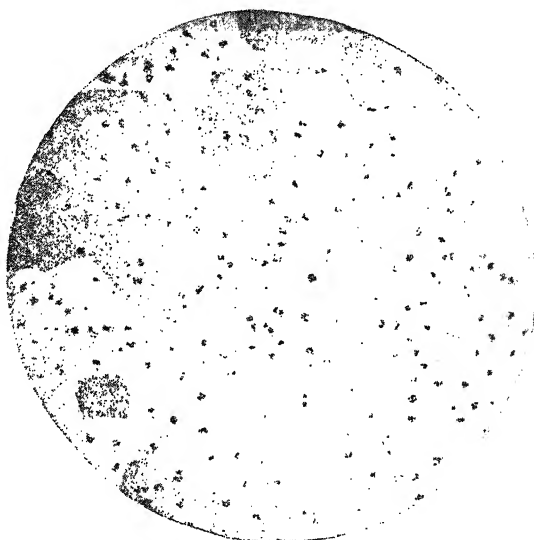


Figure 72.—Titanium-treated manganese bronze.
($\times 100$.)

tion of 0.5% of titanium copper has been made. The specks are characteristic of titanium-treated brass. The magnification is 100 diameters, and the etching was done with ammonium persulphate. Figure 73 is an ordinary manganese bronze at 20 diameters. Figure 74 shows a manganese bronze magnified 400 times. Note the small angular bright iron-zinc crystals with dark centers, scattered in the alpha (light needles) and in the beta (dark ground mass). Both figures 73 and 74 were etched with iron chloride. In figure 75 are shown large crystals of this type of brass—manganese bronze

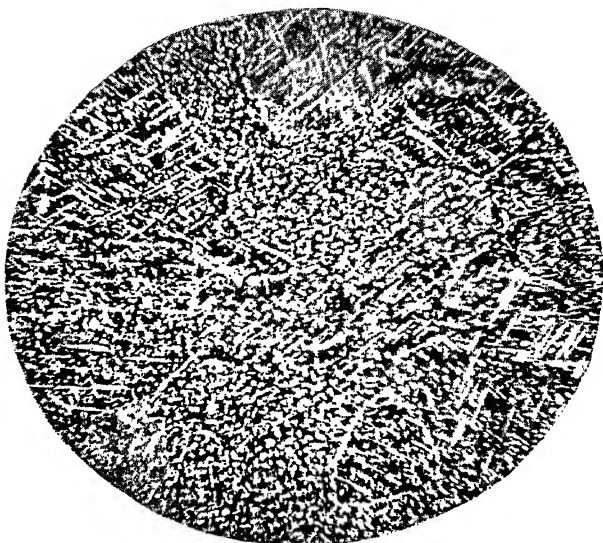


Figure 73.—Ordinary manganese bronze. ($\times 20$.)



Figure 74.—Manganese bronze at 400 diameters.

is a brass. This photograph was made at 50 diameters, and was also etched with iron chloride.

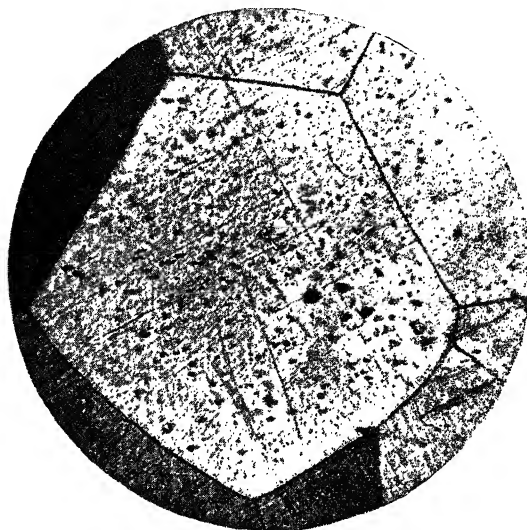


Figure 75.—Large crystals of manganese bronze. ($\times 50$.)

WHITE BRASS

Alloys of copper and zinc containing less than 45% of copper cease, as previously mentioned, to have a yellow color, the latter being, according to the content of zinc, either pure white (silver white) or a pale, but pleasing, yellow. The ductility decreasing considerably with the increase in the zinc content, such alloys cannot be used for rolling and wire-drawing; but they may be employed for castings which are to be finished by the lathe or file. Being cheap, they are well adapted for casting statuettes and other small articles not exposed to the weather. In the air, these alloys do not acquire the beautiful color of bronze known as patina, but a dirty brown-green.

Sorel's alloy.—This important and valuable alloy possesses properties rendering it especially suitable for many purposes. It is chiefly remarkable for its considerable hardness, being in this respect at least equal to good wrought iron. Its tough-

ness surpasses that of the best cast iron. In casting, it shows the valuable property of being readily detached from the mold, and it can be mechanically worked with great ease; but it is too brittle to be rolled out into sheets or drawn into wire. It is much used for casting small statues, which, after careful bronzing, are sold under the name of "cast bronze." As it rusts with difficulty and finally becomes coated with a thin, firmly adhering layer of oxide which prevents further oxidation, it may also be employed in the manufacture of articles exposed to the influence of the weather. The following mixtures have nearly the same properties, though they vary considerably in their composition: (a) 1% copper, 98% zinc, and 1% iron; and (b) 10% copper, 80% zinc, and 10% iron.

The iron is used in the shape of cast-iron shavings, which are added to the zinc. The copper is then added, and the alloy is kept fluid for some time under a cover of glowing coal, in order to ensure an intimate combination of the metals without combustion of the zinc. Being difficult to prepare the alloy in the above manner, on account of the zinc, it is recommended that in preparing large quantities not to mix the metals directly, but to use brass of known composition. This is melted down under a cover of charcoal and slightly overheated; the zinc is then added, and finally the iron.

Fontainemoreau's bronzes.—These alloys are claimed to be well adapted for chill casting, the metal being poured into iron molds, whereby the alloys become more homogeneous, separation of the constituents being prevented by the rapid cooling. By the addition of copper, iron, and lead, the highly crystalline nature of the zinc is changed. Examples of the composition of these so-called bronzes are given below, in parts:

Analysis of Fontainemoreau's bronzes

	A	B	C	D	E	F	G	H
Zinc.....	90.00	91.0	92.0	92.0	97.0	97.0	99.0	99.5
Copper.....	8.0	8.0	8.0	7.0	2.5	3.0	1.0	
Iron.....	1.0	.....	.....	1.0	0.5	.....	.....	0.5
Lead.....	1.0	1.0						

These alloys are those which, strictly speaking, belong to the brasses, the composition of the mixtures as regards their principal constituents—copper and zinc—varying only within certain limits, and the addition of tin, lead, and iron being only made to change the properties of the alloys for certain purposes.

Modern white brass alloys.—The term “white brass” is now applied to alloys consisting of tin, zinc, and copper, the base being either of the two former metals, and the copper very low, or sometimes absent entirely; occasionally the copper may be replaced with antimony.

White brasses are really babbitts containing zinc, which cheapens the alloy without materially affecting its antifrictional qualities. This alloy is used more for marine bearings than as a general babbitt, and it is more suitable for large than for small bearings. White brass lacks the free running qualities of the babbitts; it dresses badly owing to its zinc content, so that considerable difficulty is experienced in getting it to fill up the bearings properly, and for this reason it is not used for small bearings. This alloy is frequently used for sand castings, and one particular formula finds favor as a white pattern metal on account of its very low shrinkage. One of the best known formulas of white brass is Parsons' white brass, two analyses of which are here given:

<i>White brass</i>		
	A	B
	Per cent	Per cent
Tin.....	65.12	64.58
Zinc.....	31.71	33.43
Copper.....	2.87	1.95
Iron.....	0.13	0.20
Lead.....	0.17	0.02

The difference in the two analyses is very slight for all of the constituents except the copper. Alloy A was duplicated in the foundry, even to the iron content which was introduced by a flux of yellow prussiate of potash. It was found that this formula gives a close-grained metal which has considerable ductility for such an alloy. Alloy B, with less copper, was considered the better of the two for foundry use as it has more fluidity.

A number of alloys were tested by the author as follows:

White brass No. 3

	Per cent
Tin.....	60.00
Zinc.....	38.00
Antimony.....	2.00

This was found to be a very good fluid alloy which completely filled the cold ingot molds, but the metal broke easily, with a coarse fracture—large, glittering crystals. A second trial confirmed this, so this alloy, in spite of its fluidity, is not recommended:

White brass No. 4

	Per cent
Tin.....	22.00
Zinc.....	74.50
Copper.....	3.50

This was found to be a good, strong, white metal. The fracture is dense and fibrous in appearance. A second trial confirmed this, therefore, the alloy was considered suitable in cases where a cheaper alloy is required:

White brass No. 5

	Per cent
Tin.....	65.00
Zinc.....	30.00
Copper.....	2.50
Antimony.....	2.50

This alloy was found to be a very strong, ductile metal, one that will withstand considerable battering, and is easily superior to any of the foregoing alloys of this series. Its fracture shows a very fine crystallization—a nice fine grain. This alloy will be found satisfactory for a high-grade white brass.

Other alloys experimented with are as under:

White brass

No.	Tin, %	Zinc, %	Copper, %	Antimony, %
7	72.00	16.00	5.50	6.50
8	56.00	37.00	7.00	None
9	40.00	59.75	None	0.25
10	65.00	33.00	2.00	None

No. 7 alloy broke easily, and had a coarsely crystalline fracture, but it was quite sonorous. No 8 was a close-grained alloy, sluggish in flowing. No. 9 had a fracture strongly resembling that of zinc; and was considered valueless. No. 10 showed a good fracture, but appeared to flow sluggish. For white brass a selection can be made from Nos. 1, 4, and 5 alloys.

CHAPTER XVII

NICKEL ALLOYS AND MONEL METAL

Historical.—Nickel may be classed among the more modern metals. Its discovery in modern times has been attributed to Cronstedt, a Swedish chemist, in 1751; but the pure metal was not obtained until 1775. Nickel to-day is produced pure by the Mond process, perfected in 1889. In several countries nickel has been indirectly used in the preparation of alloys for centuries. As far back as the 17th century, alloys were brought to Europe from China, which were distinguished by a white color and considerable hardness, and were known by various names. The actual Chinese name *packfong*—or *packtong*—of this alloy means white copper. In 1776, Engström found it to consist of 40.5% copper, 44.3% zinc, and 15.2% nickel; while the analysis of a specimen by Fyfe, in 1822, gave 41.0% copper, 2.65% zinc, 8% nickel, and 2.7% iron. The alloy is probably prepared by the Chinese in a manner similar to that in which brass was made in Europe before zinc in a metallic state was known, namely, by fusing copper with nickeliferous minerals.

As far back as 1770, a similar white alloy, known as Suhl white copper, was prepared in Europe from white metallic grains obtained by crushing and washing old slag. According to Brandes (1823) these grains consisted of 88% copper, 8.75% nickel, 1.75% iron, silica, and alumina, and 0.75% antimony and sulphur. By adding zinc and tin an alloy was obtained which was used for spurs and gun-mountings, and contained according to Keferstein, 40.4% copper, 25.4% zinc, 31.6% nickel, and 2.6% tin. According to Frick, the alloy, whose nickel content and the white color dependent thereon was established in 1823, contained 11 parts of copper, $7\frac{3}{4}$

parts of zinc, and 1 part of nickel. In 1823, the society for promoting industry in Prussia offered a prize for the invention of an alloy which, while similar in appearance to silver, should cost no more than one-sixth the price of the latter, and be suitable for culinary and table purposes. In 1824, such an alloy was prepared almost simultaneously by Henniger Bros. of Berlin, and Dr. Geitner of Schneeberg. The latter called his alloy "argentan," and prepared it at first from cobalt speiss (on an average with 49% nickel, 37% arsenic, 7% sulphur, besides iron and other metals), the result being that the composition of the alloy was not always constant. Henniger Bros. called their alloy *neusilber* (new silver). Later on the alloy was prepared only from copper, zinc, and metallic nickel, and it was soon introduced in France under the names of *Maillechort* (called thus after the first manufacturers, Maillet and Chorier), *argent d'Allemagne*, *argent allemand*, *argent neuf*, and in England under the name "German silver."

In Vienna the alloy had been prepared since 1824, and was called *alpaka*, in Paris, *alfenide*; while the Chinese name *packfong* has been retained for inferior qualities poorer in nickel and containing other metals. Articles fairly heavily silver-plated were introduced in 1840, and are known as "China silver" or "Christophle metal."

According to other statements, the alloy known as Maillechort contains at the most 15% of nickel. Alloys which, besides copper, zinc, and nickel, contain other metals (tin, bismuth, antimony) to obtain greater fusibility and a more beautiful color, are known as "silverine," "argentan," "packfong," etc.

The uses of nickel are so many and so diverse, and are expanding so rapidly, to quote the Mond Nickel Co., as to be almost innumerable. While the employment of pure nickel is continually growing, its chief utility lies in the manufacture of alloys.

Nickel-copper alloys.—Nickel and copper unite in a wide range of proportions, the color of the alloys varying from

copper-red to the blue-white of the nickel, according to the proportions of the respective metals. With 0.10% of nickel the alloy is very ductile, of a light copper-red color, and moderate strength; with 0.15%, the ductility is still considerable, while the color changes to a very pale red; 0.25% gives a nearly white alloy, and 0.30%, a silver-white metal. The beautiful white color and considerable hardness imparted to copper by an addition of nickel make the alloy especially suitable for subsidiary coinage, and it is used for this purpose in 72 countries and territories of the world. The whole subject has been well set forth and illustrated in the booklet published free by the Mond Nickel Co. of Ontario. The number of countries issuing nickel coins is growing, and the annual mintage runs into many millions of pieces. Switzerland was the first to use nickel coins, in 1850; followed by the United States in 1857, and Belgium in 1861. To the end of 1912, all countries had issued a total of 909 million pieces of nickel coins. Many are of pure metal, while others consist of an alloy of 25% nickel and 75% copper. They offer great resistance to oxidation, are fairly hard to work, resist abrasion well, and almost defy counterfeiting. The pure coins are magnetic.

The use of alloys consisting of copper and nickel alone is limited, those consisting of copper, nickel, and zinc being more frequently employed.

Künzel and Montefiore-Levi endeavored in vain to produce a nickel-copper alloy not subject to liquation, and which, with the same or greater degree of hardness, would possess greater elasticity, more absolute strength and toughness than ordinary gun-metal. With up to 10% of nickel and 90% of copper, these alloys did not possess the required hardness; while with over 10% nickel the castings obtained were porous, because such combinations richer in nickel absorb, in fusing, large quantities of oxygen, which becomes free on cooling. By an addition of aluminum or phosphor-copper, dense castings may be obtained in iron molds. While large cavities formed as the result of too high a temperature in casting or

incorrect cooling generally yield useless castings, smaller cavities distributed throughout the entire mass disappear by rolling and stamping, and are of no disadvantage.

Nickel-copper-zinc alloys.—These alloys form the mixtures of metals known as German silver, packfong, *argent neuf*, etc. They may, in a measure, be considered as a brass, which, by an addition of nickel, has acquired a white color and considerable hardness.

Generally speaking, German silver is superior to brass as regards hardness, strength, and power of resisting chemical action, the latter property making it especially valuable for certain purposes. In respect to its preparation it is, however, a very subtle mixture, and exceedingly small quantities of foreign metals exert a considerable influence upon the physical properties of the alloy.

An alloy of iron and copper dissolves, however, readily in the German silver, and an intimate union of all the metals can be easily effected by melting together equal portions of copper and steel, and adding pieces of this alloy to the fused German silver.

An addition of silver to German silver does not affect its properties to any extent, nor does an addition of a few per cent of lead, which makes the alloy more fusible, somewhat cheaper, and improves its color.

By an addition of tin, German silver acquires considerable hardness and a beautiful sound. An alloy of this kind containing a suitable quantity of tin could be used as speculum metal, and bell-metal; but the previously given compositions for these purposes being suitable and much cheaper, tin alloys containing nickel are not used in practice.

Properties of nickel.—The properties of nickel alloys may be summed up as follows: The color of the mixture is always white, the degree of whiteness depending on the quantity of the separate metals used in the respective composition. The most beautiful color is shown by an alloy of 4 parts copper and 3 nickel; but unfortunately this alloy is scarcely available for practical purposes, it being extremely difficult

to fuse, and so hard that it can scarcely be worked. An alloy containing 75 parts copper and 25 parts nickel does no longer show a pure white color, but one with a yellowish tinge, which is clearly perceptible by holding a polished piece of such an alloy alongside a piece of silver. Hence the better qualities of German silver must in all cases contain more than one-fourth nickel. In using a small quantity of nickel, it has been attempted to remove the yellowish color by an addition of silver; but without success.

In most factories the articles made of German silver are plated with silver by the electric current, and exhibit the color of chemically pure silver, which they retain for a shorter or longer time according to the thickness of the deposit.

The mechanical manipulation of German silver is attended with some difficulties, the plates, which, for the purpose of preparing sheet must be obtained by casting, being highly crystalline and readily cracking under the hammer.

Generally, small plates about $7\frac{3}{4}$ to 12 inches long, $4\frac{3}{4}$ to $7\frac{3}{4}$ inches wide, and $\frac{1}{8}$ inch thick are prepared by casting. These plates are slightly rolled and hammered, being annealed after each mechanical manipulation. By this treatment they gradually lose the crystalline structure, and when this has entirely disappeared, can be further worked with ease, and rolled and stamped into any desired form, most articles (spoons, forks, etc.) being prepared by the latter method. Like alloys of the precious metals, German silver has the property of retaining its metallic color and luster on being brought in contact with air and water, and it is not affected even by dilute acids (lactic acid, acetic acid, etc.) such as are frequently found in food.

Nickel alloys possessing strong electric properties are used in the manufacture of positive elements for thermo-electric piles, they being especially adapted for this purpose on account of their high melting points. A thermo-electric pile, one portion of which consists of a nickel alloy, can be heated to a strong red heat without fear of the alloy melting. On

figure 76 is shown the equilibrium diagram of copper-nickel alloys according to Guertler's "Handbuch der Metallographie."

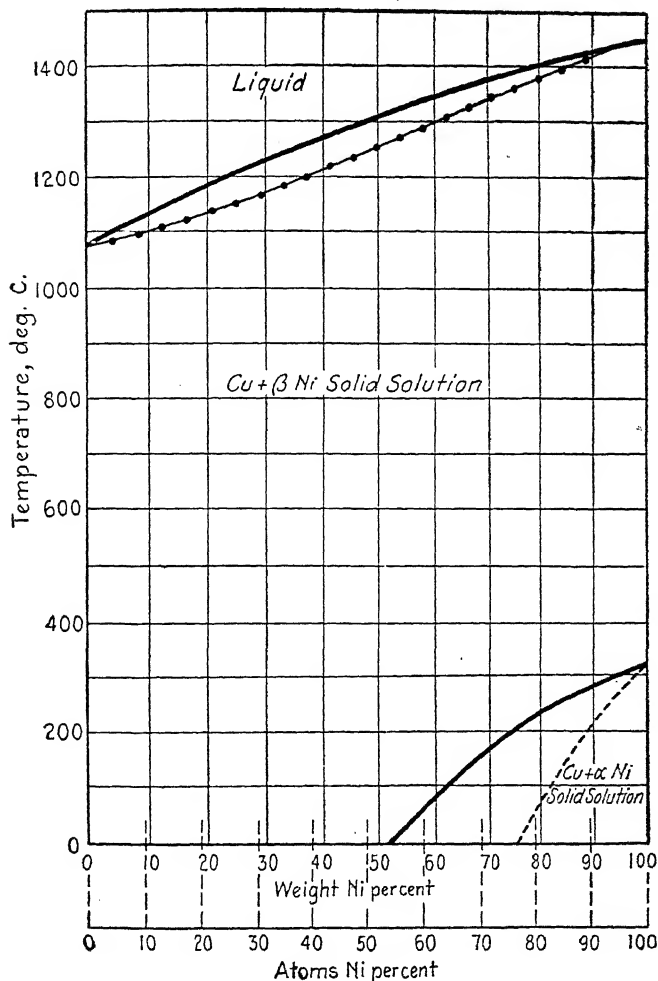


Figure 76.—Equilibrium diagram of copper-nickel alloys according to Guertler's "Handbuch der Metallographie."

Nickel alloys used in rolling-mills.—Some practical formulas for rolling-mill alloys containing nickel were given

by R. A. Wood* in a paper presented before the Institute of Metals, at the Convention held at Boston, September, 1917:

TABLE 45.—*Nickel-silver rolling-mill alloys*

Description	Nickel, %	Copper, %	Zinc, %	Iron, %	Lead, %
2%.....	2.00	65.00	33.00	None	
4%.....	4.00	64.00	32.00	"	
5%.....	5.00	64.00	31.00	"	
8%.....	8.00	62.00	30.00	"	
8% key stock.....	8.00	66.00	26.00	"	1.50
10%.....	10.00	65.00	26.00	"	
10% key stock.....	10.00	60.00	30.00	"	1.00
12%.....	12.00	62.00	26.00	"	
12% key stock.....	12.00	65.00	22.00	"	1.00
14%.....	14.00	61.00	25.00	"	
14% key stock.....	14.00	60.00	25.00	"	1.00
15%.....	15.00	60.00	25.00	"	
15% key stock.....	15.00	59.00	25.00	"	1.00
16%.....	16.00	60.00	24.00	"	
16% key stock.....	16.00	59.00	24.00	"	1.00
18%.....	18.00	58.00	24.00	"	
18% key stock.....	18.00	60.00	21.00	"	1.00
20%.....	20.00	57.00	23.00	"	
21%.....	21.00	57.00	22.00	"	
24%.....	24.00	55.00	21.00	"	
25%.....	25.00	53.00	22.00	"	
30%.....	30.00	50.00	20.00	"	
32%.....	32.00	51.00	17.00	"	

The nickel alloys, remarked Wood, are built up in the same manner as the yellow-brass alloys from a copper-zinc base, $2\frac{1}{2}$ parts of copper to 1 part of zinc answering most requirements. Tin is seldom used in connection with the nickel alloys, but iron, lead, and manganese are often used. The above mixtures present the casters weighing charges and not the analysis of the finished product. Manganese is used in small quantities, and is not considered an integral part of the alloys. A very hard nickel silver, such as is used for cutlery stock and extra hard springs, may be made by adding from 0.5 to 2% of iron to the foregoing mixtures, and by using from 4 to 5 oz. of 30% manganese copper to each 100 lb. of alloy.

* *Journal of the Institute of Metals*, vol. XI, No. 2, page 191.

Cupro-nickel.—This is made from a straight copper and nickel mixture, the nickel content varying from 5 to 25%. To make this alloy successfully, it is absolutely necessary that the melting furnace be constructed to produce a very high temperature. This is particularly true for the alloys containing the higher percentages of nickel, as the temperature must be brought up to a dazzling, white heat. It is possible to tell a good melt by noticing the surface of the molten metal; for instance, if the surface appears to be agitated and spits while the metal is being poured, it is an indication of a porous casting; and in order to make a good, sound casting, the molten metal should present a smooth and mirror-like surface. This result is difficult to obtain, except by careful attention when melting. Every precaution should be taken to avoid oxidation during the melting operation.

Alloys having high electrical resistant qualities are made by adding manganese in varying quantities to the copper-nickel alloys. These are very difficult mixtures to produce successfully, and unless their refractory nature is thoroughly understood, trouble will be encountered. The rolling of these alloys is also a difficult matter, and in order to be successfully carried out, considerable preliminary experimental work must be done. A great many alloys of this nature have been patented, many of them containing small quantities of other metals besides copper, zinc, nickel, manganese, and iron, again quoting Wood.

Alloys for sand casting.—There are many different alloys of nickel used for sand-casting purposes, and we will present a few examples, not in tabular form, but in the form of formulas that will be readily understood at a glance. Some of these alloys contain zinc and some do not. The following compositions are by analysis:

<i>Alloy No. 1. (Aterile)</i>	
Copper.....	62.40
Zinc.....	18.88
Nickel.....	12.57
Iron.....	2.94
Lead.....	1.91
Tin.....	0.71
Aluminum.....	0.08

This is a very complicated alloy, and it merely represents one analysis the author had made. There are a considerable number of different alloys known as "aterite," which is simply the trade name of one manufacturer. It is supposed to be acid-resisting. The following formula is also sometimes used:

<i>Alloy No. 2</i>	
Copper.....	65.00*
Nickel.....	9.00
Zinc.....	20.00
Iron.....	4.00
Lead.....	2.00

According to Reardon the following formulas are also used:

<i>No. 16 alloy</i>		<i>No. 99 alloy</i>	
Copper.....	38.47	Copper.....	53.92
Lead.....	42.30	Nickel.....	29.41
Nickel.....	19.23	Iron.....	5.88
		Zinc.....	10.78

<i>Malloydium</i>	
Copper.....	59.96
Nickel.....	22.82
Iron.....	0.95
Zinc.....	13.44

"Malloydium" is named after its inventor. It is a good-looking white alloy, and like the aterite alloys, is claimed to be acid-resisting. These alloys, like all other copper alloys, are resistant to some corrosive liquids, and not at all resistant to others, notably solutions of hydrochloric acid. The three alloys below are light-colored nickel silvers, suitable for making sand castings. They have no special properties, other than their white color. They are sometimes used for making plumber's brass goods which are to be nickel-plated, as a white base is to be preferred to either red or yellow brass:

<i>Nickelene</i>	<i>Per cent</i>	<i>Victor metal</i>	<i>Silver bronze</i>
		<i>Per cent</i>	<i>Per cent</i>
Copper.....	55.00	50.00	58.00
Nickel.....	12.50	15.00	16.00
Zinc.....	20.50	35.00	23.00
Lead.....	10.00	.....	2.00
Tin.....	2.00	.....	1.00
Aluminum, oz.....	.....	

These three alloys were cast by the author into round bars $1\frac{1}{4}$ inches in diameter, to determine machining qualities and color. Nickelene, the invention of A. L. Goldsmith (see *Foundry* for September, 1912) has a faint reddish-yellow shade. It machines the best and takes the smoothest finish. Victor metal has a perceptible yellow shade, which deepens on exposure. Silver bronze is whiter than Victor metal, but still has a yellow shade.

<i>No. 1 plumber's white</i>		<i>No. 2 plumber's white</i>	
Copper.....	54.00		54.00
Nickel.....	17.00		13.00
Zinc.....	27.00		25.00
Lead.....	2.00		7.00
Tin.....			1.00

No. 1 plumber's white is whiter than Victor metal, but nevertheless it has a yellow shade. No. 2 plumber's white also has a yellowish cast, but is a promising alloy for ornamental work. An increase of the nickel would mean greater whiteness.

Other white alloys give the following analysis:

<i>No. 3 Plumber's white</i>		<i>Platinoid</i>	<i>Pro-platinum</i>	
Copper.....	57.75	54.04	Nickel.....	72.00
Zinc.....	25.00	20.42	Silver.....	23.57
Nickel.....	15.00	24.77	Bismuth.....	3.72
Lead.....	1.00	0.15	Gold.....	0.71
Iron.....	1.00	0.47		
Manganese.....	0.25	0.15		

Alloys containing a considerable percentage of nickel possesses high melting points, and oil or gas-fired furnaces are more satisfactory than solid-fuel furnaces. Figure 77 shows a furnace capable of reaching a high temperature. It is built by the Caward-Gaskill Co., and it is claimed that a flame temperature of 1500°C . can be obtained, and a lining temperature of 1650° , which is sufficient for any of the alloys we have considered in this chapter; so is the furnace shown in figure 21.

Sperry * gives the following analyses of nickel alloys:

TABLE 46.—Analyses of sundry nickel alloys

	Copper	Nickel	Zinc	Iron	Cobalt
<i>Berlin alloys:</i>					
Richest.....	52.00	22.00	26.00		
Medium.....	59.00	11.00	30.00		
Poorest.....	63.00	6.00	31.00		
<i>French alloys:</i>					
Tableware.....	50.00	18.70	31.30		
".....	50.00	20.00	30.00		
Mallechort.....	65.40	16.80	13.40	3.40	
Copper-nickel alloy of the Soc. de Nickel.	48.74	49.26	(S) 0.089	0.610	(Si) 0.186
Copper-nickel of Wig- gins & Co., Birm- ingham.....	47.68	49.87	(S) 0.041	1.228	(Si) 0.136
Christofle's alloy....	50.00	50.00			
<i>Austrian alloys:</i>					
Tableware.....	50.00	25.00	25.00		
".....	55.60	22.20	22.20		
".....	60.00	20.00	20.00		
<i>Sheffield alloys:</i>					
White silver.....	55.20	20.70	24.10		
Electrum.....	51.60	25.80	22.60		
Hard alloy.....	45.70	31.30	20.00		
English.....	60.00	18.80	17.38		3.40
" elastic.....	57.00	15.00	25.00		3.00
Chinese packfong....	40.40	31.60	25.40	2.00	
Vivian's copper alloy.	48.49	50.09	.....	0.826	(Si) 0.303
<i>American alloys:</i>					
Alloy for casting....	52.50	17.70	28.80		
Bearing alloy.....	50.00	25.00	25.00		
Explosive bullet-shell.	75.50	24.10	.....	0.40	

Manufacture of German silver on a large scale.—In the manufacture of German or nickel silver, the purity of the metals used is of greater importance than in the preparation of any of the alloys previously described. The nickel on the market is generally sufficiently pure to be used without further preparation, the chief contamination being cobalt, which exerts little influence upon the properties of the alloy. Copper is frequently contaminated with iron, lead, arsenic, and antimony, and as such is only fit for the preparation of

* Transactions of American Institute of Mining Engineers, Florida Meeting, March, 1895.

German silver of second or third quality. Zinc also contains certain contaminations injurious to the qualities of the alloy.

The manufacture of German silver is generally carried on according to two methods which, from the countries where they have been perfected, are termed respectively the English and the German process. Both yield nickel silver of excellent quality, and, as will be seen from the descriptions of the two methods, differ chiefly in the manner of melting down the alloys.

German process.—The zinc and nickel to be used for a certain quantity of copper are divided into three equal portions. On the bottom of a graphite crucible, capable of holding a maximum of 22 lb. of the alloy, is placed a layer of copper, on this is put a layer of zinc and nickel, and upon this again a layer of copper. These layers are continued until all the copper is in the crucible, retaining, however, one-third each of the nickel, and zinc.

The contents of the crucible are covered with a layer of charcoal powder to prevent volatilization and oxidation of the zinc, and are melted as quickly as possible in a wind furnace connected with a high chimney, a high temperature being required for fusion of the alloy.

When the metals are supposed to be molten, they are examined by dipping in an iron rod, and if the whole is found to be thoroughly melted, an intimate mixture is effected by vigorous stirring with the rod.

The zinc and nickel held out are now added, the mass being vigorously stirred after each addition, and a high heat maintained to prevent the alloy from cooling off too much by the newly introduced metals. After the last portion has been added, another piece of zinc is generally thrown into the crucible to compensate for the loss of zinc by volatilization; and besides, experience has shown that a small excess of zinc renders the alloy more thinly-fluid, which materially facilitates the work in the subsequent casting. If the alloy is to be rolled into thin sheets it is recommended that the finished alloy be kept liquid for some time longer before proceeding

to casting. In doing this, however, it is necessary constantly to keep the surface of the molten metal covered with charcoal to prevent volatilization of the zinc.

The casting of the alloy is effected in various ways: It is either at once cast into plates, which are subsequently rolled into sheets; or cast into very thin sticks, which, after cooling, are re-melted and finally cast into plates. On account of the greater consumption of fuel and labor, the last method is somewhat more expensive than direct casting, but it has the advantage of the alloy becoming more homogeneous by re-melting; and besides it can be worked with greater ease. Only with the use of very pure metals is it advisable to cast the alloy into plates at once.

Considerable skill is required in casting the alloy, it being necessary to run it into the molds at as high a temperature as possible and in an uninterrupted stream. Any check in the stream can be at once detected by the fact that the plate is not uniform.

The molds used in casting plates consist of two iron plates, one plain and the other with a ledge corresponding to the thickness of the plate to be cast, which varies from 0.50 to 0.59 inch. On account of the great contraction of the alloy in solidifying, the distance between the two plates must be somewhat greater. In order to obtain castings of greater homogeneity, it is best to run the molten metals from below into the molds. This is effected by providing the lower plate with a lip or mouth-piece, in which is placed a clay funnel connected with a pipe rising somewhat above the mold. After the plates are tightly screwed together, the mold is highly heated, and the casting started. The metal is heated as intensely as possible, and after being freed from all contamination floating on the surface, is allowed to run in a steady, thin stream into the mold. When the metal appears on the upper end of the mold and the funnel remains filled, the casting is finished. After allowing the filled mold to stand quietly for about half an hour, the solidified plate is removed. To prevent the alloy from adhering to the sides of the mold, before cast-

ing these are coated with a layer of fine lampblack. The principal difficulty in casting plates of German silver is to obtain them perfectly homogeneous and free from blowholes, which is best effected by bringing the molten metal as hot as possible into the mold. On account of the difficulty of making the casting so quickly that the metal does not cool off, it is best to fill only one mold at a time, and replace the crucible in the furnace so as to keep the contents at the highest temperature possible.

The plates of German silver thus obtained must be carefully examined to see whether they are perfectly homogeneous. Imperfect plates are thrown out and re-melted. The perfect plates are rolled out into sheets, from which the articles to be manufactured are punched out and then further worked.

English process.—This method differs somewhat from the German, especially in the manner in which the metals are melted together, none of the zinc or nickel being held out, but the entire quantity of metal is melted at one time. Good graphite crucibles are used, which are placed in a furnace capable of producing a high temperature. The metals are used in the form of small pieces. The charge of each crucible generally consists of $8\frac{1}{4}$ lb. of tin, $\frac{1}{2}$ lb. of zinc, and, according to the quality of the alloy to be produced, 2 to 3 lb. of nickel. The metals are intimately mixed and quickly introduced into the red-hot crucibles. Their surface is immediately covered with a thick layer of coal dust, and the mixture is fused as quickly as possible. After ascertaining by stirring with an iron rod that the mass is melted, a previously prepared alloy of 1 part by weight of zinc and $\frac{1}{2}$ part of copper is added, the quantity for the above charge ranging from $1\frac{3}{5}$ and 2 lb. When this alloy is melted, and the entire contents of the crucible are homogeneous, 2 lb. of zinc is finally added. The mass, being kept constantly covered with coal dust, is now heated as strongly as possible, and when thinly-fluid a sample is taken to test its qualities.

The alloy always contains a certain amount of oxide, and,

if a large quantity is present, the casting will be porous. To ascertain how the alloy will act in casting, a test casting is made, and if the fracture of this shows blowholes, the oxides will have to be reduced. This is effected by throwing pitch into a stoneware pipe pushed through the contents of the crucible to the bottom. The products of destructive distillation evolved from the pitch effect a reduction of the oxides, which is accelerated by stirring coal dust into the molten metal. When the reduction of oxides is supposed to be finished, a strong heat is given, and, after the coal mechanically mixed with the alloy has collected on the surface, the purified metal is cast in a manner similar to that described under the German process. Instead of coating the molds with lampblack alone, many manufacturers use a mixture of lampblack and turpentine. Molds thus treated must, however, be sharply dried to volatilize the turpentine, otherwise the vapors evolved therefrom in casting might readily cause the formation of blowholes.

The casting of the plates finishes the chemical part of the process, and the perfect plates are mechanically worked in the same manner as indicated under the German process. Articles of nickel silver have to be joined with a solder whose color approaches as nearly as possible that of the alloy. An excellent composition for this purpose is prepared by melting 5 to 6 parts of German silver with 4 parts of zinc. It is, however, better to prepare the solder alloy by melting together 35 parts of copper, 57 parts of zinc, and 8 parts of nickel.

The alloy is prepared in the same manner as German silver, and, after being cast in thin plates, is pulverized while hot. If the alloy is too tough and can only be pulverized with difficulty it contains too little zinc; while too great brittleness indicates too small a quantity of nickel. In both cases the alloy must be improved by re-melting and adding the necessary quantity of the respective metals.

The alloys of nickel silver are principally used for the manufacture of tableware, such as cups, dishes, forks, spoons,

etc., but on account of their beautiful color and solidity they are also used for articles of art, and are more and more substituted for genuine silver. For fine mechanical work, German silver surpasses all other alloys, it having, besides considerable strength and power of resistance, the valuable property of not changing its appearance in contact with dry air, and of expanding but little on heating.

Manufacture of German silver sheet.—The crystalline plates obtained by casting are gradually reduced by rolling,

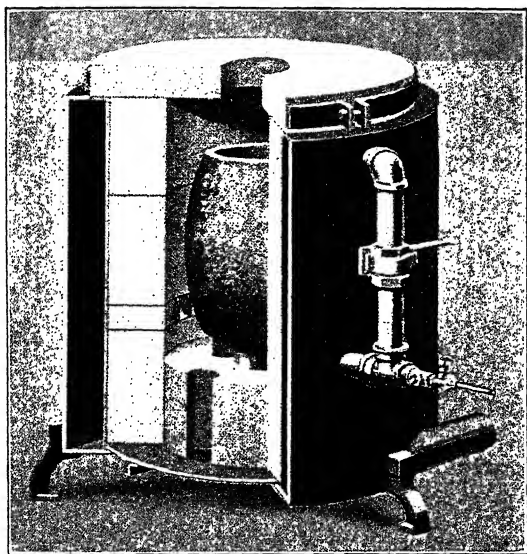


Figure 77.—High-temperature crucible furnace.

While being passed through the rolls, they are repeatedly heated to a cherry-brown heat in a furnace with direct firing, or in a muffle furnace, and allowed to cool completely, otherwise edge cracks will be formed. After the destruction of the crystalline structure, German silver can be worked like brass. Very thin sheet, $\frac{1}{40}$ to $\frac{1}{64}$ millimeter (0.001 to 0.0006 inch) thick, is called German silver foil or packfong foil.

The sheets resting on a carriage with perforated bottom,

running upon rails, are introduced into a heating furnace through an opening running the entire width of the furnace, which can be closed by a suitable door. When taken from the furnace, the sheets are placed on a carriage pushed close up to it, the upper edge just level with the furnace hearth.

Melting nickel.—Commercial nickel is a very difficult metal to handle in the foundry, first, on account of its high melting point, and secondly on account of its affinity for carbon, oxygen, and sulphur. Owing to its high melting point, very efficient melting furnaces are required, also a more refractory mold facing than that ordinarily used in making brass castings. The melting can be done with either gas or oil, and the gas may be either natural or artificial. The furnace illustrated in figure 77, which burns artificial gas, but can be adapted for oil, will melt nickel. The burner is known as the "Maxon Premix," and consists of a motor-driven blower with means for proportioning the air and gas supplied at the inlet of the blower. The air and gas are mechanically mixed within the blower, and the mixture is driven to the nozzle where complete combustion is assured.

This burner is made by the Maxon Furnace & Engineering Co. of Muncie, Indiana. Figure 29 is a reverberatory furnace suitable for melting nickel for making anodes. The facing used for the molds should be of the same nature as that used on molds for steel as the temperatures are very similar. The steel founder has learned by experience that ordinary molding sand such as used for iron is of no value to him, because it will not withstand the temperature of the molten steel, but melts and gives off gases, which produce pitted castings, and castings filled with blowholes. As the sand used in brass foundries is generally less refractory than that used in iron foundries, it follows that it is less suited than iron-molders' sand for the production of nickel castings, and that as a consequence it will fuse onto the castings, scab, and will be found very unsatisfactory. A silica sand, bonded with China clay and well milled, being dampened with a little molasses water free of sulphur, will make excellent

nickel castings, or castings of any other metal having a high melting point.

When steel is melted in the regular graphite steel-melting crucibles it will take up about 0.10% of carbon. Nickel will undoubtedly do the same, and this should be taken into consideration if malleable nickel castings are to be made. Thus, previous to 1914, castings of nickel were imported from Germany, and were used as parts of Castner sodium pots. An analysis of this nickel gave the following: Nickel, 98.34%; copper, 0.22%; iron, 0.37%; carbon, 0.53%, and silicon, 0.26%; with a small amount of sulphur. This analysis compares very favorable with "A" shot nickel, which usually has 0.50% of carbon. According to David H. Browne and John F. Thompson,* at about 0.40% carbon the separation of graphitic carbon begins to take place, also that the presence of graphitic carbon is undoubtedly harmful. Starting, therefore, with a nickel containing 0.5% carbon, care would have to be exercised to have not more than 0.10% carbon absorbed while melting, otherwise the castings would lack ductility. If the melting is done in a crucible made especially for melting steel, and a few days before being required the crucible is painted with a creamy mixture of water and alundum cement, and is then gently dried and later heated red, and a cover is luted on the crucible, there should be a minimum of contamination from carbon. A de-oxidizer should be added a few minutes before pouring, and for this purpose an alloy of nickel, magnesium, and calcium would be suitable.

An experiment made by the author will illustrate the manner in which nickel takes up carbon. In an electric resistance furnace (granular carbon) two crucibles were placed, one a clay crucible (Battersea), the other an Acheson graphite crucible. In each was placed a piece of nickel from a sodium pot casting, weighing about 5 lb. The maximum temperature of the furnace being about 1400° C., it would not melt the

* Paper presented before the A. I. M. & M. E., at Philadelphia, Sept., 1919.

nickel in the clay crucible, though it remained there for two hours; but the nickel in the carbon crucible melted after an interval, and became very fluid. When the two samples were removed it was found that the one which had been in the clay crucible was unmelted, but the nickel in the carbon crucible that had been melted was brittle and resembled cast iron; an analysis showed about 6% carbon.

Nickel anodes.—According to Sperry, the presence of carbon is desirable in nickel anodes, as its presence makes a softer anode, which will dissolve easier in the plating bath. It is, therefore, customary in melting the nickel, to place some charcoal at the bottom of the crucible, and melt the nickel twice to allow it to take up carbon. In place of this indirect method it would be better first to make a nickel-carbon alloy, and add the required quantity of this to the nickel charge. Cast anodes at one time were all alloyed, and Sperry mentions the following grades: 92%, 90%, 85%, 82%, and 80%, with a leeway of 2% plus allowed on the nickel content. They are sold on the actual nickel content. The charge for a 90% anode consists of 92 lb. of nickel, 4 lb. of old files, and 4 lb. of tin.

Flux for nickel alloys.—In melting, a flux composed of 3 parts lime and 1 part fluorspar is frequently used. To make it, new lime is slaked the same as for mortar, and the fluorspar is mixed therewith in proper proportion; the mixture is allowed to dry, then broken up, and finally pulverized. About 2% of this flux is used as a covering for the metal. According to Madsen, in a paper presented at the meeting of the American Electrochemical Society, April 23, 1921, the so-called 97–98% cast anodes containing manganese were found to deteriorate the bath most rapidly, while anodes of the same nickel content containing tin performed little better, and introduced the difficulty of forming metastannic acid under certain conditions. The so-called 92–96% cast anodes containing iron maintained the bath nearly constant, but their efficiency was rarely 100% on their nickel content, and the large amount of ferric hydrate caused considerable difficulty in making heavy deposits. Madsen also found that the ratio of the anode to cathode surface was more important than

usually supposed, and was apparently a function of the anode composition. It was in all cases necessary to have from two to five times greater anode than that of cathode surface, and in some cases from 10 to 15 times.

The use of relatively pure nickel was then tried, both imported and domestic, the latter made by the International Nickel Co., which has a refinery in New Jersey, but its main plant is in Ontario. Neither was entirely satisfactory until the so-called cold-rolled malleable nickel was tried. This type of anode was found to dissolve with an efficiency of about 97% when free from passive portions. The average analysis of this material is as follows:

Average analysis of cold-rolled malleable nickel. (Madsen)

Nickel.....	95.30
Iron.....	2.13
Copper.....	0.25
Manganese.....	0.33
Carbon.....	0.30
Silicon.....	0.23

The two following lists of commercial alloys containing nickel (tables 47 and 48) were compiled by Paul D. Merica, superintendent of research for the International Nickel Co.:

TABLE 47.—Composition of nickel alloys used in manufactured products

Name	Common use	Nickel, %	Copper, %	Zinc, %	Lead, %
30 Per cent	.....	30	46.67	23.33	
25 "	.....	25	50	25	
20 "	Spoon stock.....	20	60	20	
20 "	.....	20	53.33	26.67	
18 "	Spoon stock.....	18	65	17	
18 "	.....	18	72	10	
18 "	Bolster silver.....	18	65.50	16	0.50
18 "	Spring silver.....	18	54.67	27.33	
18 "	Spinning silver.....	17.50	67	15.50	
16 "	.....	16	67	17	
16 "	Bolster silver.....	16	56	28	
15 "	.....	15	60	25	
15 "	.....	15	56.67	28.33	
12 "	.....	12	58.67	29.33	
12 "	Spinning silver.....	12	66	22	
12 "	Key stock.....	12	60	26	2.0
12 "	" ".....	12	65	22	1.0
10 "	.....	10	62	28	
10 "	.....	10	60	30	
8 "	.....	8	61.33	30.67	
5 "	.....	5	72		
5 "	.....	5	63.33	31.67	

TABLE 48.—Some names and compositions of nickel silver

Name	Copper, %	Nickel, %	Zinc, %	
Extra white metal.....	50	30	20	
White metal.....	54	24	22	
Arguzoid.....	48.5	20.5	31	
Best best.....	50	21	29	
Firsts or best.....	56	16	28	
Special firsts.....	56	17	27	
Seconds.....	62	14	24	
Thirds.....	56	12	32	
Special thirds.....	56.5	11	32.5	
Fourths.....	55	10	35	
Fifths, for plated goods....	57	7	36	
Alfenide.....	50-70	10-20	5-30	
Alpakka.....	65.2	13	19.5	
Amberoid.....				
Argentan.....	50-70	10-20	5-30	
Argentan solder.....	35	8	57	
Argentin.....				
Argiroid.....				
Argozoil.....	54	14	28	Sn 2; Pb 2; Orn. Casting
Arguzoid.....	55.78	13.45	23.2	Sn 4.03; Pb 3.54
Argyrolith.....	48.5	20.5	31	
Aterite.....	50-70	10-20	5-30	
Carbondale silver.....	55-60	12-18	13-20	Pb 1-2.5; Fe 6-10
Colorado silver.....	66	18	16	
China silver.....	57	25	18	
Craig gold.....	50-70	10-20	5-30	
Electro plate.....	80	10	10	
Electrum.....	50-70	10-20	5-30	
German silver.....	51.5	26	22.5	
Keen's alloy.....				
Lutecin.....				
Maillechort (typical French analysis).....	66.2	16.4	13.4	Pb 0.15; Fe 3.2; Sn 22
Markus alloy.....				
Neogen.....	58	12	27	Sn 2; Al 0.5
Nevada silver.....				
New silver.....				
Nickelin.....	68-55	31-32	0-13	For resistance wire
Nickelin.....	74.5	25	.....	Fe 0.5
Nickel oreide.....	66-87	5-10	0-10	
Platinoid.....	54.04	24.77	20.42	Fe 0.5; Mn 0.5
Platinoid.....	60	14	24	W 1-2
Popes Island metal.....	70	14	15	I
Potosi silver.....				
Ruolz alloys.....				
Spoon metal.....				
Silveroid.....				
Silverite.....				
Silverine.....				
Sterline.....	68	17-18	13-14	Fe $\frac{1}{2}$ - $\frac{3}{4}$
Sterlin.....	68.5	17.88	12.84	Pb 0.76
Suhler white copper.....	40.4	31.6	25.4	Sn 2.6; Co 0.5-0.6

TABLE 48.—Some names and compositions of nickel silver—Continued

Name	Copper, %	Nickel, %	Zinc, %	
Tutenay.....	45.7	17.3	37	Ag 2; FeO $\frac{1}{2}$
Victor metal.....				
Virginia silver.....				
Weiss kupfer.....				
White metal.....				
White copper.....				
Wessells silver.....	51-65	19-32	12-17	

Brief descriptions of other alloys are as follows:

Nickel-zinc alloy.—Powdered nickel, 1 part, and powdered zinc, 2 parts, when heated, yield an alloy of a blackish-violet powder and brittle metallic globules. A powder of zinc, 90 parts, and nickel, 10 parts, serves in painting and for silver printing.

Aphtit.—The alloy known by this name is composed of 66 parts iron, 23 parts nickel, 4 parts tungsten, and 5 parts copper.

Arguzoid.—This alloy is silver-white, almost ductile, and suitable for articles of art, and contains 55.78% copper, 23.198% zinc, 13.046% nickel, 4.035% tin, and 3.544% lead.

Manganin.—Copper, 83; nickel, 4; manganese, 13.

Dienett's German silver.—This alloy is said to possess a beautiful white color, and the density and toughness of tombac. It is composed of copper, 4; zinc, 2.5; lead, 0.75; nickel, 0.5; and tin, 0.125.

Pirsch's patented German silver.—This is composed of the following:

Composition of Pirsch's German silver

Copper	Nickel	Cobalt	Zinc	Antimony	Aluminum	Iron
79.50	16.00	1.00	1.00	1.00	0.50	1.00
75.00	16.00	2.00	2.25	2.75	0.50	1.50
71.00	16.50	1.25	7.50	2.50	.....	1.25

Alfénide, argiroide, and allied alloys.—The alloys sold under these and many other names consist in most cases of

a mixture of metals closely resembling German silver, but they are always electroplated with pure silver, the thickness of the plating depending on the price of the respective articles. In many cases the composition used in the manufacture of these articles is a very ordinary quality of German silver, which alone would present a mean appearance, but is hidden from the buyer by the silver-plating.

Nickel-aluminum alloy.—An alloy of 20 parts nickel and 8 parts aluminum gives threads suitable for lace, etc.

Silver-bronze.—This term has been applied to an alloy for bars, sheet, and wire. It is composed of manganese, 18 parts; aluminum, 1.20; silicon, 5.00; zinc, 13; and copper, 67.50 parts. Its electrical resistance is claimed to be greater than that of German silver.

Rosëin.—This alloy is used for jewelry. It is composed of nickel, 40 parts; silver, 10; aluminum, 30; and tin, 10 parts.

Martino's hard alloys.—These are used for drilling and cutting tools and consist of pig iron, 17.25 parts; ferro-manganese, 3; chromium, 1.5; tungsten, 5.25; aluminum, 1.25; nickel, 0.5; copper, 0.75 and wrought iron, 70.5; or, pig iron, 17.25 parts; ferro-manganese, 4.5; chromium, 2; tungsten, 7.5; aluminum, 2; nickel, 0.75; copper, 1; and wrought iron, 65 parts.

NICKEL STEEL

According to the Mond Nickel Co., the greater part of the nickel produced is employed in nickel steel. That the demand is considerable is shown by the growth in the output of nickel from the Sudbury district of Ontario, where, in 1902, the total was 5945 tons, while in 1916 it was 41,299 tons. An alloy of nickel and iron is no novelty, as practically all native iron—of terrestrial and meteoric origin—contains nickel. In 1889, Henry Schneider, of Creusot, France, took out two patents for the manufacture of alloys of cast iron and nickel and steel and nickel, respectively. He stated in his specifications that he had found it very difficult to incorporate nickel with iron and steel on a commercial scale. He therefore first

made a preliminary alloy of cast iron and nickel by charging nickel scrap and pig iron together in a reverberatory furnace, under a layer of anthracite to avoid oxidation. An alloy was thus made containing from 5 to 30% nickel, which was remarkable for its elasticity and strength. This mixture of iron, nickel, and carbon was then used as a "mixing alloy" in the preparation of steels with varying content of nickel, notably a 5% nickel steel which was found suitable for ordnance, armor-plate, gun-barrels, projectiles, and other military equipment, as was very natural.

The subject of nickel steel is so extensive that a volume could be written concerning it, so only the important features will be discussed here. The chief characteristic distinguishing nickel steel from simple steel is its high elastic strength, and the following comparison shows the different properties of the two steels:

Comparison of medium carbon and medium nickel steels

	Carbon steel	Nickel steel
Carbon, %.....	0.20	0.38
Nickel, %.....	None	3.50
Elastic limit, lb. per sq. in. (minimum).....	30,000	60,000
Ultimate tensile strength, lb. per sq. in. (minimum).....	60,000	105,000
Modulus of elasticity.....	29,000,000	30,000,000
Safe working stress in tension, lb. per sq. in.	16,000	28,000

Nickel steel is of great importance in bridge construction, and some of the greatest bridges in the world are largely of this alloy. In any bridge, by using nickel steel throughout, the saving in weight is from 10 to 30%, and in cost up to 12%, according to the Mond Nickel Co.

A considerable amount of investigation has been done on nickel steels by the U. S. Bureau of Standards, and its Circular No. 58 deals with "invar," and is worth consulting. A few remarks on invar and related nickel steels from an article written by Paul D. Merica, and published in *Chemical and Metallurgical Engineering* of March 2, 1921, is quoted in

part below. Dealing with invar and similar alloys, Merica said that, beginning at 25% of nickel, the thermal expansivity of the ferro-nickel alloys at 20° C., diminishes rapidly with increasing nickel content up to about 34%, thereafter again increasing; first rapidly, and then more slowly to that of pure nickel. These curious changes are utilized in the manufacture of three patented alloys, namely, "invar," "dilver," and "platinite," all having a thermal expansivity very low at ordinary temperatures, nearly equal to that of glass and platinum. The values are given in the table below:

TABLE 49.—*Thermal expansivity of iron-nickel alloys*

Nickel, %	Mean coefficients of linear expansion $\times 10^6$	Nickel, %	Mean coefficients of linear expansions $\times 10^6$
0	10.354+0.00523 <i>t</i>	44.4	8.508-0.00251 <i>t</i>
5.0	10.529+0.00580 <i>t</i>	48.7	9.901-0.00067 <i>t</i>
19.0	11.427+0.00362 <i>t</i>	50.7	9.824+0.00243 <i>t</i>
26.2	13.103+0.02123 <i>t</i>	53.2	10.045+0.00031 <i>t</i>
27.9	11.288+0.02889 <i>t</i>	70.3	11.890+0.00387 <i>t</i>
28.7	10.387+0.03004 <i>t</i>	100.0	12.661+0.00550 <i>t</i>
30.4	4.570+0.01194 <i>t</i>	12.2+1 Cr	11.714+0.00508 <i>t</i>
31.4	3.395+0.00885 <i>t</i>	16.8+1 Cr	11.436+0.00170 <i>t</i>
34.6	1.373+0.00237 <i>t</i>	16.2+2.5 Cr	19.496+0.00432 <i>t</i>
35.6	0.877+0.00127 <i>t</i>	21.3+3 Cr	18.180+0.00426 <i>t</i>
37.3	3.457-0.00647 <i>t</i>	34.8+1.5 Cr	3.580-0.00132 <i>t</i>
39.4	5.357-0.00448 <i>t</i>	35.7+1.7 Cr	3.373+0.00165 <i>t</i>
43.6	7.992-0.00273 <i>t</i>	36.4+0.9 Cr	4.433-0.00392 <i>t</i>

Invar contains about 36% of nickel and has a mean linear thermal expansivity of approximately 0.000001 per degree C. between 0 and 40° C. It melts at 1425° C., has a density of 8.0 grams per cubic centimeter, and an electrical resistivity of about 80 microhm-cm. It is very resistant to corrosion in water, and may be immersed in it for days without the appearance of rust spots. Platinite is similar, except that it has a thermal expansivity equal to that of platinum (approximately 0.000009 per degree C.) and contains about 46% of nickel. Dilver has a thermal expansivity coefficient of 0.000008 per degree C. Invar, as well as the other alloys of similar character and composition, may be rolled, drawn, and

machined; and is used for the manufacture of measuring tapes, length standards, instruments and chronometers of high accuracy for which temperature-length changes must be almost wholly eliminated. These and similar alloys are produced now in the United States. Perhaps the principal present use for platinite is for the sealing-in wire of electric lights.

MONEL METAL

Monel metal is a comparatively new alloy discovered and patented January 30, 1906 by Ambrose Monell, who gave it his own name. In the patent specifications (U. S. patent, 811,239) it is described as an alloy of nickel and copper obtained by reduction of the ore. According to H. S. Arnold, in "Monel Metal; Its Suitability for Waterworks Use," August, 1921, the ore deposits in the Sudbury district of Ontario, from which monel is derived, are the largest known nickel deposits in the world—in fact, they constitute 80% of the world's supply of the metal. The largest producing property is the Creighton mine, one of the holdings of the International Nickel Co. The Mond Nickel and British American Nickel Companies are the other operators in that district. The ore contains considerable sulphur, about half of which is eliminated by heap roasting. The roasted ore is then smelted in blast-furnaces to a matte containing about 25% of nickel and copper. This matte is blown in Bessemer converters to approximately 80% nickel and copper. This product called Bessemer matte is shipped to the refinery where it is pulverized, dead-roasted to remove sulphur, and finally reduced with charcoal in oil-fired reverberatory furnaces, to monel metal. (See figure 29.)

The furnaces are tapped at about 2850° F., and after deoxidizing in the ladle with manganese and magnesium, the metal is chill-cast into ingots for rolling and forging, and into blocks for re-melting purposes. Monel for sheet metal and for re-melting carries about 0.25% manganese; while for rods, forgings, and wire, the manganese is raised to 2.5%.

Metal for sand castings usually has 1% of silicon added. The alloy—monel metal—thus produced, contains approximately 67% nickel, 28% copper, and 5% other metals, chiefly iron, manganese, and silicon. Monel metal is a single solid solution which looks, and in general, acts like a pure metal. There has been no separation nor any addition of nickel or copper during the refining process. The nickel-copper ratio remains the same from ore to finished metal, hence the name “natural alloy.”

Monel metal can be cast, forged, rolled hot, or drawn cold. It may be autogeneously welded, brazed, soldered, stamped, machined, and polished. It is annealed by heating to 900° C. It is hardened only by cold work.

Foundry difficulties.—Troubles with monel metal are due to the following causes:

1. On account of its high nickel content it has a higher melting point than the alloys ordinarily used in brass foundries, and ordinary brass-melting furnaces melt the alloy with difficulty; consequently it has to be kept in the furnace for a long time, during which period it absorbs both sulphur and oxygen which later may react and liberate sulphur dioxide, as much as 80% of which may be retained by the metal upon solidification, resulting in porous castings.

For small castings, crucible melting is preferred, and they should be heated in gas or oil-fired furnaces, and not in solid-fuel furnaces. The latter will melt the alloy, just as they will melt steel, but to accomplish this the fires must be more skillfully operated than is usual in melting copper or its alloys. With oil or gas, the temperature can be kept at any reasonable point sufficiently long to melt these refractory metals, and that is what is important—to keep up the temperature until the metal is liquid. With solid-fuel furnaces, the temperature drops with each addition of fresh fuel made to replenish that consumed; this delays the melting unless the furnaces are operated as they must be operated to melt steel. In melting monel metal, the ordinary brass crucible is not suitable as its softening point is too low, and it may collapse when the

tongs are tightened around it. The steel-melting crucible is much better for high temperatures, even when white hot it will maintain its shape under the pressure of the tongs.

2. A second difficulty with monel metal is that of running the metal into the molds to produce complete castings. Its high nickel content renders it rather viscid. If the castings are not expected to withstand pressures of gas or liquids, a little aluminum added to the mixture will help matters materially. Monel metal also requires deoxidizing like copper, otherwise, it is likely to make spongy castings. An alloy of magnesium and copper makes a good deoxidizer, as a slight increase in the copper content will work no harm: about 1% of a 10% magnesium-copper will help to get sound castings.

As a covering on the metal while it is being melted, some foundrymen recommend charcoal, as used for brass. However, a flux is better, and the same flux as used for nickel has been recommended. What is required is a flux that will melt to a fluid slag and cover the metal.

Silicon is added to deoxidize, also to make the metal run more smoothly; sometimes lead may be present and in such cases silicon is inferior to aluminum for this purpose.

For large castings, monel metal is melted in oil-fired reverberatories, or in electric furnaces such as are used for melting steel. The Monel Metal Corporation uses both types of furnaces, the oil-fired furnace is known as the Gamm furnace (figure 29). This type of furnace has also been used for melting nickel for casting anodes. The burners are shallow troughs or pans, arranged in tiers. The oil is flowed into each pan separately, and is just ignited and burns with natural draft. The same type of furnace, namely, natural-draft, oil-fired pan burner, has been used extensively for melting steel in crucibles—in fact, it was the first oil-fired furnace used for melting steel or wrought iron.

Analysis of monel metal.—The composition of monel metal is likely to vary, and the following analyses made by Sperry illustrate this point:

Variations in composition of monel metal. (Sperry)

Specimen	Copper, %	Nickel, %	Iron, %
4 cast bars (average).....	24.76	70.50	5.24
2 rolled bars (average).....	25.86	72.10	2.04
2 drawn bars (average).....	26.52	72.60	0.88
1 rolled bar.....	25.70	73.90	0.40

The U. S. Navy specifications for cast monel metal are nickel, 60.00% minimum; manganese, 2%; iron, not more than 3%; and copper, the remainder. For rolled monel metal, nickel, 60%; aluminum, 0.50% maximum; iron, 3.50% maximum; and copper the remainder.

The physical properties must be 65,000 lb. tensile strength; 32,500 lb. yield point, and 25% elongation in 2 inches. For rolled sections one inch square in area and less, the minimum tensile strength must be 84,000 lb.; yield point, 47,000 lb.; and elongation, 25% in 2 inches. On cross-sections over 1 inch square: tensile strength, 80,000 lb.; yield point, 45,000 lb.; and elongation, 28% on 2 inches.

The specifications of the Bureau of Steam Engineering differ a little from those of the Navy Department. For instance, for castings: nickel, 60% minimum; copper, 33%; iron, 6.50%; aluminum, 0.50%; and lead, none. For ingot metal: nickel, 60%; copper 38%; and manganese, 2%. For rolled monel: nickel, 60%; copper, 36%; iron, 3.50%; aluminum, 0.50%; and lead, none.

While the high melting point of monel metal is responsible for the greater part of the difficulties encountered with it in foundries, it has also advantages; thus it loses comparatively little in strength at temperatures that seriously injure other and lower melting point metals and alloys. At 1000° F., monel metal loses about 20% of its original strength. A bronze such as 88-10-2, at 700° F. loses approximately 42.5% of its tensile strength and practically 100% of its elongation. A bronze, which at an increase of 700° F. loses over 40% of its tensile strength, and drops from 11 to 0.25% elongation (Dewrance) is utterly unsuited for service where

it will be exposed to such an increase of temperature. Monel metal at 1000° F. higher is stronger than the bronze was originally.

Physical properties of monel metal.—The physical properties of monel metal as given by H. S. Arnold, previously cited, are to the effect that its tensile strength forged or rolled runs from 75,000 to over 100,000 lb. per sq. in., depending upon the amount of work and the finishing temperature. The elastic limit will be from 40,000 to 75,000 lb. per sq. in.; elongation, 30 to 50% in 2 inches; and reduction of area, 50 to 70%. Monel metal is comparable to an annealed medium steel in hardness, its Brinell numbers running from 145 to 170. The Shore scleroscope hardness is about 27. The yield point under compression runs from 60,000 to 70,000 lb. per sq. in.

Values for torsional strength of hot-rolled monel metal are, yield point, 50,000 to 80,000 lb. per sq. in.; and maximum stress 75,000 to 90,000 lb. per sq. in. Shear tests give for double shear 90,000 to 127,000 lb., and for single shear, 45,000 to 60,000 lb. per sq. in. A research laboratory (G. & J. Weir, Limited, Cathcart, Scotland) has recently made a series of comparative Izod impact tests on several different metals with monel metal at the top of the list. The metals compared were $\frac{3}{4}$ inch, rolled mild steel rod; wrought iron; rolled brass; forged copper; rolled monel metal rod; cast Admiralty gun-metal, iron cast in green sand, and high-tension bronze cast in chill. The results are expressed in foot-pounds absorbed in breaking or bending, and follow in the order of their magnitude:

Comparison of impact tests on various metals

Cast iron.....	0.8
Admiralty metal.....	8.0
Rolled brass.....	23.0
High-tension bronze.....	25.0
Forged copper.....	46.0
Wrought iron.....	58.4
Mild steel.....	76.7
Monel metal.....	113.7

All pieces were broken in the test except copper, wrought

iron, mild steel, and monel metal. Tests by the U. S. Bureau of Standards at Washington, D. C., verify these figures, and give monel metal a higher figure than heat-treated alloy steels of twice its tensile strength.

The physical properties of monel metal may be tabulated as follows for convenient reference:

Physical properties of monel metal. (Arnold)

Specific gravity, as cast.....	8.87
Specific gravity, rolled.....	8.98
Coefficient of expansion between 70 and 212° F. (15% greater than steel, and 18% less than copper).....	0.0000765 per deg
Electrical resistance, ohms per mil foot.....	256
Temperature coefficient, per ° F.....	0.0011
Melting point, ° F.....	2480
Heat conductivity, compared with copper.....	$\frac{1}{18}$
Shrinkage, cooling from molten state, inch per foot..	0.25
Modulus of elasticity, lb. (about).....	25,000,000
(same as wrought iron, and twice as great as brass)	
Ultimate strength (sand cast), lb. per sq. in.....	75,000
Yield point (sand cast), lb. per sq. in.....	40,000
Elongation, % in 2 inches.....	30
Hardness:	
Shore.....	20
Brinell.....	100

Resistance to corrosion.—Monel metal has a good reputation for resisting the corrosive influences of acids, alkalies, and chemical salts. No metal will resist all corrosive agents, thus monel is not suitable for use in sulphite digesters or in valves conveying hot sulphite liquors, as it is less resistant than bronze for such work; but for the majority of corrosive agents it resists better than bronze. It has one advantage, its rate of corrosion is slow, and it corrodes evenly with little pitting or local attack. It has a high resistance to atmospheric corrosion, such as fresh or salt water, wet or superheated steam, gases of combustion, metallic mercury, and the oxidizing influence of heat up to 1000° F.

Tests have proved that such acids as benzoic, citric, hydrofluoric, lactic, dilute phosphoric, picric (in the cold), salicylic, tannic, hydrocyanic, and carbolic acid have practically no effect on the metal. The evidence seems sufficient that it is resistant to all fruit and fatty acids and phenols. The action

of food is not severe on monel metal, and food may stand in vessels of this metal for some time without acquiring a foreign flavor. The exceptions to this rule are tomatoes and clams. They have been found to be affected by long standing in vessels of monel metal to the extent they were rendered unfit for food.

Monel metal is slightly attacked by pure alkalis, but there have been exceptions to this rule, cases in which the alloy has been definitely attacked by alkalis in the presence of their salts.

Principal uses of monel metal.—It is used for structural purposes where it will be exposed to severe weather conditions. It has been found suitable for roofing sheets, skylight frames, window screens, and window frames. It is very satisfactory for fly screening, especially when exposed to sea-water spray and sea breezes. This makes it suitable for the window sills, window frames, door frames, and the lanterns of lighthouses, which are frequently made of a high-tin bronze. It is a good metal to use in connection with superheated steam; wet steam and hot water, in the shape of valve-seats, bushings and stems, pump rods and plungers, meter parts, and stopcocks. It also finds application in oil-combustion parts, spray-valves, ignition points, welding torch-heads, conveyers, and stirrers for furnaces, internal-combustion engine valves, glass rollers, and blowpipes. Its usefulness for these purposes is due to its high tensile strength at elevated temperatures.

A somewhat recent use of the metal is for golf clubs.

In chemical work, monel metal is used for pickling crates, pins, tie-rods, nuts and washers, evaporating and drying pans, foudrinaire cloth, filter-cloth, and many other uses. It is interesting to note that in the Pittsburgh, Pa., district, monel metal is used for metal parts exposed to sulphuric acid pickle. Monel metal does not withstand hydrochloric acid with uniformity; sometimes it withstands it well, at other times not at all. Each case should be experimentally decided before investing any considerable sum in monel metal. It is probably true that monel metal will resist hydrochloric acid better than

any other common alloy. In no case is monel metal recommended for nitric, chromic, perchloric, hot picric, or phosphoric acids; or for such oxidizing salts as ferric sulphate, copper sulphate, mercuric chloride, or molten zinc salts. Neither will it resist molten metals or molten sulphur. It resists well the action of dry chloride and sulphur gases. Monel metal is also gaining a reputation as a material of construction used by waterworks' engineers, for chlorinating parts such as valve-stems, valve-seats, and filter-screens, and for meter and pump parts.

Monel metal in the form of scrap is sometimes used in brass foundries for introducing nickel into brass and bronze. Such scrap should never be used for this purpose, even if the monel metal alone gives good results. Scrap monel, especially sheet scrap in the form of punchings, is likely to be contaminated by iron or steel. Great care should be used in alloying with monel scrap of unknown origin, as it is so easy to mix in some form of iron which is so difficult to detect and remove before it gets into the bronze or other copper alloy. When nickel is to be added to brass or bronze it is always more economical to use the 50-50 copper-nickel alloy than to use scrap monel, or even scrap nickel of uncertain origin. Nickel has been given the undeserved reputation of producing spongy castings, because some form of nickel-bearing scrap has been used for the sake of cheapness, with bad results. Such scrap has been known to introduce considerable sulphur, as well as iron into bronze, both of which elements, when so introduced, are likely to be harmful to a foundry's reputation. Use pure clean metals to introduce nickel into bronze or brass, also add a little deoxidizer, and the results will be very satisfactory, both from an acid-resisting and strength standpoint.

The following tests made by the Bureau of Standards illustrate the value of nickel in bronze, when used in place of tin. The 88-10-2 alloy was taken for the experiment, and instead of 5% of tin, 5% of nickel was used, making the following alloy:

Value of nickel in place of tin

	Per cent
Copper.....	88.00
Tin.....	5.00
Nickel.....	5.00
Zinc.....	2.00

The physical properties were as follows:

Ultimate strength, lb. per sq. in.....	40,680
Yield point, lb. per sq. in.....	13,050
Elongation, % in 2 inches.....	31.8
Reduction of area, %.....	28.0
Modulus of elasticity, lb. per sq. in.....	17,300,000

A second alloy tested was the following:

	Per cent
Copper.....	89.00
Tin.....	4.00
Nickel.....	4.00
Zinc.....	3.00
Ultimate strength, lb. per sq. in.....	39,675
Yield point, lb. per sq. in.....	11,500
Elongation, % in 2 inches.....	31.2
Reduction of area, %.....	31.2
Modulus of elasticity, lb. per sq. in.....	14,900,000

It was not stated how the nickel was introduced, but it must be properly done, otherwise good results such as just given cannot be expected. If scrap contaminated with iron and heavily loaded with sulphur is used the result will be disappointment, but the nickel is not to blame.

CHAPTER XVIII

TIN ALLOYS

TIN is distinguished by its white color and permanency when exposed to the air. Although soft itself, it has the property of hardening many other soft metals. It is seldom worked alone, but is as a rule alloyed with another metal whereby its comparatively slight hardness is increased, and it also becomes more thinly-fluid and more capable of being cast. The metal most commonly used for alloying with tin is lead, which combines with it without difficulty in all proportions by weight. Figure 78 is an ingot of Banka (Dutch East Indies) tin.

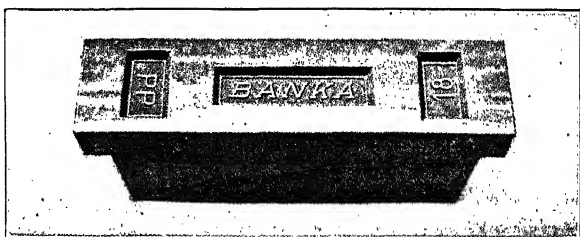


Figure 78.—Ingot of tin.

Tin-lead alloys.—These alloys are easily made. Lead added to tin increases its malleability and ductility, while its properties are not materially impaired; its tenacity, however, is decreased. Difficult to break even after successive bendings, tin becomes more brittle when alloyed with lead. The fracture is then more marked than that of lead, whatever may be the proportions in the alloy, the latter metal being more readily separated than tin, but requiring, nevertheless, to be torn asunder. The strongest alloy of tin and lead is produced by mixing 3 parts of tin with 1 part of lead. The

density of this alloy is 8. According to Watson, the densities of tin-lead alloys are as follows:

Density of tin-lead alloys

Tin	Lead	Density	Tin	Lead	Density
0	1	11.3	8	1	7.6
10	1	7.2	4	1	7.8
32	1	7.3	2	1	8.2
16	1	7.4	1	1	8.8

Alloys of tin and lead were formerly much used in the manufacture of domestic utensils. They are, however, not suitable for this purpose, on account of the solubility and poisonous properties of the lead. Under no circumstances should an alloy of tin and lead used in the manufacture of domestic utensils contain more than 10 to 15% of lead. Such an alloy is not sensibly attacked by vinegar and fruit acids, but unfortunately there are cases in which the so-called tin contains as much as one-third of its weight of lead.

Alloys containing from 10 to 15% of lead have a white color, are considerably harder than pure tin, and are much cheaper. Many alloys of tin and lead have an especially lustrous appearance, and are used for stage jewelry and for mirrors for reflecting the light of lamps, etc. An especially lustrous alloy is known as "Fahlun brilliants." It is used for stage jewelry and consists of 29 parts tin and 19 parts of lead. The alloy is poured into molds faceted in the same manner as diamonds. Seen in an artificial light, the pieces of metal thus cast are so brilliant that they produce the effect of diamonds. Other alloys of tin and lead of some importance are those used in the manufacture of toys (tin soldiers, for instance). They must fill the molds well and be cheap, consequently, as much as 50% of lead is used. With the use of sharp iron or brass molds such an alloy yields good castings. Toys can also be prepared from type metal, which is even cheaper than alloys of tin and lead, but has the disadvantage of readily breaking on bending the articles sharply.

In the following table are given the melting points of alloys of tin and lead, as determined by Parkes and Martin:

TABLE 50.—*Melting points of tin-lead alloys*

Tin	Lead	Melting point, ° F.	Tin	Lead	Melting point, ° F.
4	4	372	4	28	527
6	4	336	4	30	530
8	4	340	4	32	532
10	4	348	4	34	535
12	4	336	4	36	538
14	4	362	4	38	540
16	4	367	4	40	542
18	4	372	4	42	544
20	4	378	4	44	546
22	4	380	4	46	548
24	4	382	4	48	550
4	4	392	4	50	551
4	6	412	4	52	552
4	8	442	4	54	554
4	10	470	4	56	555
4	12	482	4	58	556
4	14	490	4	60	557
4	16	498	4	62	557
4	18	505	4	64	557
4	20	512	4	66	557
4	22	517	4	68	557
4	24	519	4	70	558
4	26	523			

For baths used by cutlers and others in tempering and heating steel articles, Parkes and Martin proposed the following alloys:

Lead-tin tempering baths

No.	Use	Lead	Tin	Melting point, ° F.
1	Lancets.....	7	4	420
2	Other surgical instruments.....	7½	4	430
3	Razors.....	8	4	442
4	Pocket knives.....	8½	4	450
5	Knives, scalpels, etc.....	10	4	470
6	Chisels, garden knives.....	14	4	490
7	Hatchets.....	19	4	509
8	Table knives.....	30	4	530
9	Swords, watch springs.....	48	4	550
10	Large springs, small saws.....	50	4	558
11	Hand saws.....	Oil boiling		600
12	Articles of low temper.....	1	4	612

Britannia metal.—The alloy known under this name consists principally of tin alloyed with antimony. Many varieties contain only these two metals, and may be considered tin hardened by antimony. Other alloys, also called Britannia metal, contain in addition, certain quantities of copper, sometimes lead, and occasionally, though rarely, bismuth.

The Pewterer's Company of England, which has been an incorporated society ever since the reign of Edward IV. (1474), in 1772 attempted to regulate the quality of pewter wares by permitting enough lead to bring the density of pewter from $\frac{1835}{20}$ to $\frac{1885}{20}$ that of tin. Persons who departed from this regulation were liable to expulsion from the guild, but it has been so greatly disregarded as to have very little effect in keeping up the standard of pewter.

Britannia metal has always a silvery color with a bluish tinge; and, on account of its hardness, takes a fine polish, which it retains on exposure to the air. Though it is hard, in strength it only slightly surpasses tin. Good Britannia metal shows a fine-grained, jagged fracture; if the fracture be fairly coarse and strongly crystalline, the alloy contains too much antimony, and, as a rule is too brittle to be worked to advantage.

Even with a correct composition, the brittleness of this metal is such that in rolling it into sheet the edges generally become full of cracks. Some iron or zinc increases this brittleness to a considerable extent; and, in preparing an alloy to be rolled out into sheet or to be used for stamped articles, great care must be taken to have the metals used entirely free from iron or zinc.

It is well known to makers of babbitt metals that zinc is injurious, because it drosses the metal; nevertheless, at one time Britannia metal was made containing zinc, as the following formula shows: Tin, 85.50%; antimony, 10.50%; zinc, 3.00%; and copper, 1%. The advantage of adding zinc is difficult to understand, and later the alloy (English Britannia metal) was altered to the following composition: tin, 90%;

antimony, 8%; and copper, 2%. One American manufacturer added manganese, although this causes tin alloys to dross excessively. The composition used was: tin, 109 lb.; antimony, 9 lb.; copper, 1.25 lb.; and 30% manganese copper, 12 oz. For hollow ware the following composition was used extensively: tin, 92.50%; antimony, 5.75%; and copper, 1.75%. Britannia metal finds extensive use for making hollow ware for table use as it can be easily worked into complicated shapes by spinning and stamping, without the necessity of annealing. It is then silver-plated, and being white in color, when the silver plate wears off, the article does not look as unsightly as it would if made from some metal such as German silver which assumes a yellow shade after the coating of silver disappears.

The composition of Britannia metal is very similar to that of "genuine" babbitt (tin, 89%; antimony, 7.50%; copper, 3.50%) and the same methods are used in making the alloy. The alloys are always better mixed when made with a hardener, which introduces into the base metal the proper quantities of the alloying metals. In this case the latter have a higher melting point than the base metal, which is the reverse of copper alloys. The hardener contains the copper and antimony, with sufficient tin to make a low melting composition, which is melted in an iron kettle with the proper proportion of tin. The alloy is mixed thoroughly and poured into molds, which for rolling purposes make flat slabs. The molds are of cast iron, and they are covered with a flat plate, and the pouring end is raised to put pressure on the metal forming the slab. Like other metallurgical operations, it requires skill to produce a slab free from flaws, and which can be rolled successfully.

The rolling is done with chilled-iron rolls capable of making a sheet up to 24 inches in width. The sheet is worked up by spinning, drawing, and stamping into the shapes required. Before being silver-plated, the objects have to be cleaned, which is accomplished, first, with a wet tampico wheel using

fine pumice stone and water; and after a thorough scouring it is passed through a hot potash solution to remove grease, then into a mercury dip, known as the "quick or blue dip." This consists of a small amount of corrosive sublimate and sal-ammoniac dissolved in water. This deposits a thin film of mercury on the metal surface without which the silver might peel or strip. The article is removed from this dip, rinsed, and immersed in a "strike," which is a silver-plating solution very low in silver. This deposits a very thin film of silver which clings tenaciously, and is rooted to the surface of the base metal. From one to two hours deposit is now given in a regular silver-plating solution, where the desired thickness of silver is put on. This is now scratch-brushed, then buffed with a soft wheel and fine rouge to produce a high polish. Cheap goods with light deposits of silver are usually lacquered, but high-grade goods are given a deposit of sufficient thickness to withstand cleaning and scouring.

Tin-antimony-copper alloys.—The following table is taken from a paper presented by William Campbell, at the Cleveland meeting of the American Institute of Mining Engineers, in 1912:

TABLE 51.—*Composition of tin-antimony-copper alloys*

Name	Tin, %	Antimony, %	Copper, %	Lead, %	Zinc, %	Bismuth, %
English Britannia...	94.00	5.00	1.00			
Bearing alloy.....	91.00	4.50	4.50			
Britannia sheet.....	90.60	7.80	1.60			
" cast.....	90.60	9.20	0.20			
" 	90.00	6.00	2.00	.....	.....	2.00
Babbitt.....	90.00	7.00	3.00			
" 	89.30	8.90	1.80			
Pewter.....	89.40	7.00	1.80	1.80		
Queen's metal.....	88.50	7.10	3.50	.....	0.90	
Jacoby metal.....	85.00	10.00	5.00			
Ashberry metal....	77.80	19.40	2.80			
Dewrance metal....	33.33	44.50	22.00			

Other alloys known as Britannia metals are the following:

TABLE 52.—*Composition of so-called Britannia metals*

Britannia metal	Tin, %	Antimony, %	Copper, %	Zinc, %	Lead, %	Bismuth, %
English.....	81.90	16.25	1.84			
".....	90.62	7.81	1.46			
".....	90.1	6.3	3.1	0.5		
".....	85.4	9.66	0.81	3.06		
Pewter.....	81.2	5.7	1.60		1.15	
".....	89.3	7.6	1.8		1.8	
".....	83.30	6.60	1.60	3.06		1.60
Tutania.....	91.4		0.7	0.3	7.6	
Queen's metal.....	88.5	7.1	3.5	0.9		
German.....	72	24	4			
".....	84	9	2	5		
" (cast).....	20	64	10	6		
Malleable (cast)....	48		3	48		1
Birmingham (sheet)..	90.60	7.80	1.50			
" (cast).....	90.71	9.20	0.09			
Karmarsch's.....	85.0	5.0	3.60	1.40		1.60
Koeller's.....	85.70	10.40	1.00			1.80
Wagner's (fine).....	85.64	9.66	0.81	3.06		0.83

A large amount of antimony imparts great hardness and a permanent brilliant luster to Britannia metal, but it decreases its ductility. Moreover, the antimony possessing poisonous properties, its use must be restricted; especially if the alloy is to be employed in the manufacture of domestic utensils, such as coffee and teapots, etc. It need scarcely be said that for obvious reasons the antimony must be free from arsenic, and besides, a very small amount of it renders the alloy extremely brittle, and articles manufactured from it tarnish quickly, especially on exposure to moist air. Alloys consisting of tin and antimony alone would seem to deserve the preference, and a 90–10 tin-antimony mixture can be especially recommended for its resistance to chemical influences and for its facility of working.

For most purposes not requiring a special degree of hardness, this alloy is the most suitable, it being readily fusible and filling out the molds well. For articles subjected to constant wear a harder alloy is required.

Working Britannia metal.—This metal can be brought into any desired shapes by pressing and rolling, which will be referred to later on, but always being more or less brittle, it is preferred to prepare many articles by direct casting. To obtain clean and good castings requiring but little dressing, it is best to use brass molds. Before casting, the molds should be well heated, and the interior lined with a special coating to prevent the alloy from adhering. This is effected by means of a mixture of lampblack and turpentine, or by lampblack alone; and, though the first process is the more simple and convenient, the latter is preferable, especially for casting fine articles. The molds may be so coated as to be smooth and uniform by using an ordinary lamp, similar to a spirit lamp, filled with turpentine. By holding the cold mold over the dull flame it becomes coated with a delicate film of a velvety black soot, which, while it preserves all the fine lines of the mold, prevents the alloy from adhering thereto.

Instead of lampblack, some manufacturers use finely elutriated redden or red chalk mixed to a uniform mass with water. With molds having many small, and at the same time, deep turns, it is difficult to coat the inside perfectly with the protecting mass, and the coating with lampblack is decidedly to be preferred.

With ordinary molds it is, of course, impossible to cast in one piece an article which is to have a certain shape. The different parts are consequently cast separately, and subsequently put together with a solder of a color as nearly like that of the metal as possible. Such articles can, however, be also cast in one piece. Take, for example, a coffee-pot, an article frequently made of Britannia metal, whose shape is such that it must consist of several pieces. To cast it in one piece, the mold must be so constructed that it can be completely removed from the finished castings.

The separate parts of the mold having been coated with lampblack or clay are put together, and the whole heated nearly to the temperature of the molten metal. The latter is then poured into the mold until it seems to be entirely

filled. After waiting until it may be supposed that a sufficiently thick layer of metal has solidified, the mold is quickly turned over to allow the still liquid portion of the metal to run out.

In order to obtain castings of the right condition, this procedure requires considerable skill, it being necessary to hit the exact moment at which the layer of metal has acquired the required thickness, and before succeeding the operator must be prepared to have many failures; but by noting the time allowed to pass between pouring the metal into the mold and pouring the still liquid portion out, the exact time required for the formation of a sufficiently thick layer will soon be learned.

The inside of the articles obtained by this mode of casting is sometimes roughly crystalline. This is due to the metal beginning to crystallize, and the corners and edges of the small crystals being exposed by pouring out the liquid portion of the metal. Care must therefore be taken to use for such castings an alloy giving a fine-grained mass. The interior of the articles, as far as accessible, can also be smoothed—while the article is still in the mold—with a burnishing stone or burnisher.

For articles to be made by stamping or other mechanical processes, the alloy resulting from melting the metals together is ladled into cast-iron boxes, and the slabs thus made are subsequently rolled into sheet. Spherical vessels are usually “spun up” in halves, which are then united by soldering; while smaller articles are generally pressed in molds by a stamping press of very simple construction.

Cast or stamped Britannia metal has always an unsightly gray-white appearance, the innumerable small crystals of which the surface of the article is composed preventing a complete reflection of the light. The articles must, therefore, be polished, which is effected with a burnisher; or, if their shape permits, on a lathe by means of wooden discs covered with leather rubbed with emery.

Biddery metal.—The name of this alloy is derived from Biddery, a city in the East Indies. It may be classed among

Tin Alloys

the alloys known under the collective term of Britannia metal, but differs from it in containing lead instead of antimony. Genuine Indian Bidderly metal, which is frequently imitated in England, consists of 3.5 to 11.4 parts of copper, 93.4 to 84.3 parts of zinc, none to 1.4 parts of tin, and 3.1 to 2.9 parts of lead.

According to Hamilton, who had occasion to witness the operation, 123.6 parts of zinc, 4.6 parts of copper, and 4.14 parts of lead, together with a mixture of resin and wax to prevent oxidation, are melted together in a crucible. The fused metal is poured into clay molds, and the articles are finished on a lathe. The Indian artists impart to the articles a beautiful velvety-black color by treatment with a solution of copper sulphate, and decorate the surface in a very peculiar and original manner. By means of a graver, lines frequently forming very artistic designs are cut into the surface. The lines are then inlaid with fine gold and silver wire, pressed in by means of a burnishing tool, after which the articles are carefully polished. The beauty of the black coating, being somewhat marred by the manipulation, is restored by treating the articles with a solution of copper sulphate, sal-ammoniac, and niter, finally polishing with very fine abrasives.

The finished articles have a peculiar appearance, the gold and silver designs on a velvety-black ground presenting frequently a striking resemblance to an embroidery executed in gold and silver threads on black velvet.

There are several other alloys somewhat resembling Britannia metal which are known under various names, two of which are given below:

Ashberry metal

Copper.....	2.0	79.0
Tin.....	80.0	79.0
Antimony.....	14.0	15.0
Zinc.....	1.0	2.0
Nickel.....	2.0	1.0
Aluminum.....	1.0	

Minofof metal

Copper.....	3.26	4
Tin.....	67.53	66
Antimony.....	17.00	20
Zinc.....	8.94	9
Iron.....	.....	1

This alloy, as well as Ashberry metal, is employed for making forks and spoons, coffee-pots, teapots, and all similar articles generally made of ordinary Britannia metal, are composed of 9 parts of tin and 1 part of antimony. In fact, Britannia metal surpasses both the Ashberry and Minoform metals in beauty, but the latter are harder.

White metals and bearing alloys.—The so-called white metals contain varying quantities of tin, copper, and antimony. Sometimes the last mentioned is replaced by zinc, the composition in this case approaching more or less that of statuary bronze. The simultaneous use of zinc and antimony seldom occurs. There are some alloys which contain iron or lead besides the tin, copper, and antimony. A combination of many metals to one and the same alloy does not seem especially practicable, since our knowledge of the alloys has scarcely reached such a point as to enable us to determine with absolute certainty how three metals in various proportions of mixture behave toward each other; and we are still less able to state definitely the behavior of alloys in the preparation of which four, five, or even six metals are used. Besides, experience has frequently shown such alloys to be of no value, and are simply recommended by some persons in order to make a market for a new product.

The so-called white metals serve almost exclusively for bearings. An exact line is drawn between the various kinds of bearings, and they can be chiefly divided into two large groups, namely, red-brass bearings and white-metal bearings. The former are distinguished by great hardness and power of resistance, and are principally used for bearings of heavily loaded and rapidly revolving axles. For the bearings of shafting of large, heavy fly-wheels revolving at great speed, those of red brass are also preferable to white metal, though they are more expensive.

White metals are cheaper than red-brass alloys, and have a lower melting point, so that a worn-out bearing can be readily re-melted and replaced by a new one; while with red brass these operations are much more troublesome and expensive. White-metal bearings possess still another property

which makes them almost indispensable for certain purposes: If, for instance, the shafting resting in the bearing does not run quietly, the result of the use of a red-brass bearing will be that either the axle or shafting or the bearing—according to whether the one is harder than the other—is subjected to great wear, and this will in a short time increase to such an extent that the axle or shafting in revolving will swerve considerably. However, by using white-metal bearings of a sufficient degree of softness, the harder axle or shafting, by pressing into the softer bearing, runs more quietly for a longer time than if the latter consists of red brass. The bearing, of course, wears out as fast, but this is of little importance, since the expense of replacement is comparatively small.

White-metal bearings contain a preponderating quantity of tin. The degree of hardness of such alloys depends chiefly on the copper content. The tin can, however, be also considerably hardened by the use of antimony, and such bearings are frequently used, they being much cheaper than those containing copper, though they are not so strong, and are generally brittle, so that they frequently break.

Structure of white-metal alloys.—By a metallographic examination* of congealed white-metal of tin, antimony, and copper, three different constituents can be distinguished, as follows:

1. Acicular crystals of a chemical combination of copper with tin according to the formula CuSn with about 35% copper and 65% tin, which are first separated from the liquid solution. They are the hardest constituents and crumble readily, leaving behind shallow, sharp-edged depressions, which, according to Behrens, promote the distribution and adhesion of the lubricant.

2. Cubical crystals of a tin-antimony alloy, harder than tin, but less hard and brittle than the above-mentioned copper-tin crystals, also softer than antimony.

3. Nearly pure tin as eutectic alloy enclosing the pre-

* Charpy. Bulletin de la Société d'Encouragement, 1898 and 1899.

viously mentioned crystals. It is soft and plastic. According to Charpy, this yielding property of the alloy is of importance for decreasing friction in case the shafting or journal is not accurately aligned in the bearing. The latter adapts itself to the shape of the shafting or journal, while a disproportionate influence is exerted upon the harder bronze bearings, the places which are more heavily loaded undergoing greater friction and wear.

When the bearings run hot, the structure of the alloy becomes more coarsely crystalline and its behavior is less favorable.

Proportions of white-metal alloys.—The proportions by weight of the constituents of white-metal vary considerably. Tin is the most expensive of the metals entering into their composition, and, if for this reason there should be the temptation of limiting and replacing it by lead, it must be considered that an alloy rich in lead is softer than one rich in tin; and that an attempt to overcome this drawback by increasing the antimony content would cause increased brittleness, hence a tendency of the parts toward breaking. An increase in the copper content above about 5% would not only increase the brittleness but also the melting point, and hence doubly injurious.

For the white-metal bearings of the Berlin Railroad, 4 lb. of copper was first melted, and to this was added 8 lb. of antimony, and then 24 lb. of pure tin. The alloy was cast in plates 15 millimeters (0.59 inch) thick, and 40 lb. of these were melted together with 40 lb. of tin, overheating being avoided as far as possible, and again cast in plates, which were then ready for use. The alloy therefore contained about 83% tin, 11% antimony, and 6% copper. It is of importance that the metals be as pure as possible, especially containing no lead and zinc, and that larger quantities of metal should not be melted at one time.

The bearing metal used by the Austrian Northwest Railroad was of a similar composition, it containing 82 parts of tin, 12 parts of antimony, and 6 parts of copper.

Bearing metals.—In table 53 will be found the composi-

tion of the more frequently used bearing compounds, selected with regard to hardness and wear:

TABLE 53.—*Composition of white metals for bearings*

Purpose	Tin %	Anti- mony %	Zinc %	Iron %	Lead %	Copper %
German, for light loads.....	85	10	.....	.....	.....	5
“ “ “	82	11	.....	.....	.....	7
“ “ “	80	12	.....	.....	.....	8
“ “ “	76	17	.....	.....	.....	7
“ “ “	3	1	5	.....	3	1
“ “ heavy loads.....	90	8	.....	.....	.....	2
“ “ “	86.81	7.62	.....	.....	.....	5.57
British for heavy loads.....	17.47	.....	76.14	.....	.....	5.62
“ “ medium loads....	76.7	15.5	.....	.....	.....	7.8
“ “ “	72.0	26.0	.....	.....	.....	2.0
For mills.....	15	.....	40	.....	42	3
“ .....	.....	1	5	.....	5	.....
“ .....	.....	1	10	.....	2	.....
For heavy axles.....	72.7	18.2	.....	.....	.....	9.1
“	38	6	47	.....	4	1
For rapidly revolving axles..	17	77	.....	.....	.....	6
Bearings of great hardness...	5	.....	.....	70	.....	2.5
“ “ “	12	82	2	.....	.....	4
Bearings (cheap).....	2	2	88	.....	.....	8
“ “ “	1.5	1.5	90	.....	.....	7
For railroads:						
Prussia.....	91	6	.....	.....	.....	3
“	85	10	.....	.....	.....	5
“	80	12	.....	.....	.....	8
Prussian and Hanoverian railroads approved under the heaviest pressure.....	86.81	7.62	.....	.....	.....	5.57
Bavaria, durable cold run- ning.....	90	8	.....	.....	.....	2
Austrian government rail- road.....	90	7	.....	.....	.....	3
Distributing slide-valves....	83.2	11.2	.....	.....	.....	5.6
Railroad cars and larger machines.....	.....	16	.....	.....	84	.....
Railroad cars, harder and {	20	20	.....	.....	60	.....
stronger.....	.....	12	.....	8	80	.....

As will be seen, iron is only used in rare cases, and the mixtures containing lead find but little application, experience having shown that the strength of the alloy is considerably decreased by the addition of lead.

Bearings of soft metals are now frequently replaced by such as consist of a metal whose hardness is almost equal to that of which the axle is made, phosphor-bronze being often

used for this purpose, as it can be readily obtained as hard as an axle of wrought or cast steel. The metal is then used in a very thin layer, and serves to fill out the small interspaces formed by wear on the axle and bearing, the latter consisting simply of an alloy of tin and lead. Such bearings, though very durable, are rather expensive, and can only be used for larger machines. For smaller machines, bearings of white metal are generally preferred, and, if the axles are not too heavily loaded, give excellent service.

Babbitt antifriction metal.—The original babbitt metal is made by melting together 4 parts by weight of copper, 12 parts of Banca tin, and 8 parts of antimony, and adding 12 parts by weight of tin after fusion. The antimony is added to the first portion of tin, and the copper is introduced after taking the melting pot from the fire and before pouring into the mold. This alloy is called hardening. The "lining metal" consists of this hardening, melted together with twice its weight of tin, thus making it consist of 3.7 parts copper, 7.4 parts antimony, and 88.9 parts tin. The bearing to be lined is cast with a shallow recess to receive the babbitt metal. The portion to be tinned is washed with alcohol and powdered with sal-ammoniac, and those surfaces which are not to receive the lining metal are to be covered with a clay wash. The portion to be tinned is then warmed sufficiently to volatilize a part of the sal-ammoniac, and is then tinned. The lining is next cast in between a "former," which takes the place of the journal and the bearing.

The German Admiralty specifications for babbitt metal required 6 parts of tin to be combined with 1 part of copper, while 6 additional parts of tin were to be alloyed with 1 part of antimony in a separate crucible. When both of these alloys were thoroughly liquefied, they were brought together by pouring the one into the other, and mixing thoroughly. The alloy thus obtained was then poured into ingots, and re-melted before being used for filling bushings, or interspacing slide-valves.

Miscellaneous white alloys.—A number of alloys of varying composition are given in table 54:

TABLE 54.—*Miscellaneous white alloys*

Name	Purpose	Zinc %	Copper %	Tin %	Anti- mony %	Nickel %	Lead %	Iron %	Carbon, arsenic, phos- phorus %
Penton's.....	Axle-boxes for locomotives	80	5.5	14.5	8				
Dewrance.....	Locomotive bearings.....	.....	4	6	.....			
.....	Antifriction brasses.....	80	5	14	.....	I			
.....	Stopcocks.....	72	7	21	.....			
English.....	"	I	2.4	53	10.6	.....	33		
Jacoby's.....	Machines.....	.....	5	85	10	.....		
Hoyle's.....	Pivot bearings.....	.....	.....	24	6	.....	22	0.55	
Carnelia.....	"	10.20	70.20	4.25	.....	.....	14.75	Trace	
Antifriction.....	"	.....	1.60	98.13	.....	.....	.....
White metal.....	"	.....	.....	.....	.....	.....	87.92		
.....	Lining car brasses.....	.....	.....	Trace	15.10	.....	84.87		
Salgee antifriction.....	"	85.57	4.01	9.91	.....	.....	1.15		
Graphite.....	"	.....	.....	14.38	.....	.....	67.73		
Carbon bronze.....	Bearings.....	.....	75.47	9.72	.....	.....	14.57	.....	C (trace)
Cornish bronze.....	"	Trace	77.83	9.60	.....	.....	12.40	Trace	
Magnolia metal.....	"	"	Trace	.....	16.45	.....	83.55	"	
American antifriction.....	"	0.98	.....	.....	19.60	.....	78.44	0.65	
Tobin bronze.....	"	38.40	59.00	2.16	.....	.....	0.31	0.11	
Graney bronze.....	"	.....	75.80	9.20	.....	.....	15.06		
Damascus bronze.....	"	.....	76.41	10.60	.....	.....	12.52		
Ajax metal.....	"	.....	87.24	10.98	.....	.....	7.27	{	As or P
Harrington bronze.....	"	42.67	55.73	0.97	.....	.....	.....	0.68	(0.37)
.....	Car-boxes.....	Trace	84.33	.....	14.38	.....	.....	0.61	
Ex. B. metal (Dudley's).....	"	.....	76.80	8.00	.....	.....	15.00	.....	P (0.20)

The last 16 alloys given in table 54 are from analyses made by C. B. Dudley with the Pennsylvania Railroad, and published in the February, 1892, *Journal of The Franklin Institute*. His Ex. B. metal wears 13% slower than phosphor-bronze. To obtain uniform castings he added 0.2% of phosphorus. The formula is 105 lb. of copper, 60 lb. of phosphor-bronze (new or broken), $9\frac{3}{4}$ lb. of tin, and $25\frac{1}{4}$ lb. of lead.

In table 55 following are given some modern babbitt and antifriction alloys, as compiled by the author of this book:

TABLE 55.—*Composition of babbitt and antifriction metals*

	Tin, %	Copper, %	Anti- mony, %	Lead, %
Genuine for heavy service.	89.00	3.00	8.00	
Calumet & Hecla, A. C. No. 1.	83.50	5.50	11.00	
Standard for heavy work.	60.75	3.75	10.50	25.00
Metallic packing (German).	53.30	0.15	0.50	64.30
Dardelle's metal (P. R.R.).	10.00	.....	18.00	72.00
Moore-Jones armature.	86.95	5.00	7.80	
Magnolia metal.	5.00	.....	15.00	80.00
Genuine babbitt.	89.00	3.50	7.50	
International Aircrafts Standards Board. . .	91.00	4.50	4.50	
S. A. E. Specification No. 24.	84.00	7.00	9.00	
Railroad truck babbitt.	5.00	.....	10.00	85.00
Freight journal bearings. . . . .	.....	.....	13.00	87.00
Terne metal.	18.50	.....	1.75	80.25
Magnalium metal.	3.88	0.04	17.81	78.27
Generator bearing 60 to 90 lb. dead load unit pressure.	85.00	5.00	10.00	78.27
Gas engine bearings.	15.00	.....	10.00	75.00
Ordinary service, steady load in one direc- tion.	5.00	Bi 0.05	9.50	85.00
Motor metal.	85.00	Cu 8.25	8.25	
Soda-fountain fittings.	87.00	Cu 3.00	10.00	
Richards plastic babbitt.	82.43	Cu 8.10	9.47	
Street-car motor bearings.	85.00	Cu 5.00	10.00	
Signs and letters. . . . .	.....	.....	13.00	87.00
Soft metal trays.	10.00	.....	10.00	80.00
Britannia metal hall-marked.	92.00	2.00	6.00	

The last table in this chapter gives the properties of various babbitts, as compiled for the American Society for Testing Materials:

TABLE 56.—Physical properties of white-metal bearing alloys

Alloy No.	Chemical formula				Deformation of cylinder $1\frac{1}{4}$ in. diam. by $2\frac{1}{2}$ in. high at 70° F., inches			Brinell hardness		Melting point		Complete liquation point		Specific gravity	Weight		Proper pouring temp. $^{\circ}$ F.
	Cop- per, %	Tin, %	Anti- mony, %	Lead, %	At 1000 lb.	At 5000 lb.	At 10,000 lb.	At 70° F.	At 212° F.	$^{\circ}$ F.	$^{\circ}$ C.	$^{\circ}$ F.	$^{\circ}$ C.		oz. per cu. in.	grams per cu. in.	
1	4.5	91.00	4.50	None	0.0000	0.001	0.015	28.6	12.8	437.0	225	699.8	371	7.34	4.24	120.28	824
2	3.5	89.00	7.50	"	0.0000	0.0015	0.0120	28.6	12.7	460.4	238	683.6	362	7.39	4.27	121.10	808
3	3.33 $\frac{1}{3}$	83.33 $\frac{1}{3}$	8.33 $\frac{1}{3}$	"	0.0010	0.0045	0.0070	34.4	15.7	462.2	239	791.6	422	7.46	4.31	122.25	916
4	3.0	75.00	12.00	10.00	0.0005	0.0025	0.0090	29.6	12.8	365.0	185	555.8	291	7.52	4.35	123.23	680
5	1.0	65.00	15.00	18.00	0.0010	0.0030	0.0090	29.6	11.8	365.0	185	536.0	280	7.75	4.48	127.00	661
6	3.5	20.00	15.00	63.50	0.0015	0.0050	0.0180	24.3	11.1	365.0	185	517.6	267	9.33	5.39	152.89	638
7	None	10.00	15.00	75.00	0.0010	0.0050	0.0230	24.1	11.7	464.0	240	500.0	260	9.73	5.62	159.44	625
8	"	5.00	15.00	80.00	0.0020	0.0090	0.0620	26.9	10.3	469.4	243	500.0	260	10.04	5.80	164.52	625
9	"	5.00	10.00	85.00	0.0040	0.0120	0.0840	19.5	8.6	469.4	243	491.0	255	10.24	5.92	167.80	616
10	"	2.00	15.00	83.00	0.0010	0.0100	0.1540	17.00	8.9	473.2	245	500.0	260	10.07	5.82	165.02	625
11	"	None	15.00	85.00	0.0010	0.0100	0.1190	17.00	9.9	476.8	247	500.0	260	10.28	5.94	168.46	625
12	"	"	10.00	90.00	0.0025	0.0170	0.2850	14.3	6.4	476.8	247	509.0	265	10.67	6.17	174.85	634

CHAPTER XIX

LEAD ALLOYS

WHILE a great deal of lead is used in the manufacture of sheet, pipe, foil, and the like; and more in making white lead for paint, alloys of the metal with others are many and of great importance.

An addition of other metals generally makes lead harder and more or less injures its ductility. Copper imparts greater hardness without impairing its ductility to a serious extent, and if the copper content be low, such an alloy can be drawn into pipe or rolled out to thin sheet. Arsenic, antimony, and tin increase the hardness of lead, but impair its ductility considerably; the two former especially exerting a strong influence in this respect, while the lead-tin alloys retain their ductility. Lead-antimony alloys containing less than 22% of antimony contract on cooling, and are therefore not suitable for sharp castings; only mixtures richer in antimony expand on cooling and reproduce the finest impressions of the mold. The hardness of lead-antimony alloys increases with the antimony content, those with 11 to 17% being about four times as hard as lead, and with 23.5% five times. More antimony makes the alloys still harder (with over 25%, 12 times as hard as lead), but on account of their brittleness they are not suitable for technical purposes. The affinity of zinc and iron for lead being low, it is difficult to prepare alloys with them.

Classes of alloys.—Lead alloys include antifriction metals, die-casting metals, type metals, and shot metal. Any alloy having lead as a base is classed under the term "lead alloys." The list in table 57 can be regarded as antifriction metals.

Type metals.—To be suitable as a type metal, an alloy must allow of being readily cast, fill the molds sharply, and

TABLE 57.—Lead-base antifriction metals

Name	Use	Lead %	Anti- mony %	Tin %	Cop- per %	Mag- nesium %	Zinc %	Nickel %	Iron %	Ar- senic %	Bis- muth %	Cad- mium %
Lead tape.....	Electric conductors.....	95.0	4.5	0.5								
Kneiss alloy.....	Machine bearings.....	42.0	.....	15.0	3.0	....	40.0					
Bearing alloy.....	In sugar mills.....	62.5	16.0	20.0	1.5							
Glyco.....	".....	UR	14.0	12.0								
Glyco turbo.....	".....	70.0	22.0	8.0								
Hoyle's metal.....	".....	42.0	12.0	46.0								
Navy bronze, No. 4.....	".....	44.0	16.0	36.0	4.0							
Babbitt.....	Hardware.....	25.0	75.0*									
Pattern alloy.....	".....	87.0	13.0									
Acid metal.....	Lead pumps.....	52.0	8.0	35.0	5.0							
Graphite alloy.....	Bearings.....	68.0	17.0	15.0								
Standard antifriction.....	".....	50.0	10.0	40.0								
Magnolia (ordinary).....	".....	80.0	15.0	5.0								
" (slightly harder).....	".....	77.0	17.0	6.0								
".....	Pipe and roofing.....	94.0	6.0									
".....	High-speed shafting.....	76.5	15.0	8.0	0.5							
".....	Dynamo bearings.....	72.0	15.0	12.0	1.0							
".....	".....	66.7	.....	25.0	.....	.....	.....	.....	.....	.....	8.3	.....
Expanding alloy.....	Bearing metal.....	77.7	16.8	5.9	.....	.....	.....	.....	.....	.....	.....	1.25†
Tandem.....	".....	86.75	6.0	6.0	.....	.....	.....	.....	.....	.....	.....	.....
Patent non-shrinking.....	To generate hydrogen.....	66.69	32.63‡									
Hydrene.....	Metallic packing.....	70.0	13.0	17.0								
White metal.....	Packing joints.....	92.0	8.0									
".....	Coffins.....	85.41	12.48	2.11								
Babbitt.....	Spindles.....	78.25	16.25	5.25	0.25							
Corrosion resisting§.....	Lead pipe.....	91.00	.....	.....	4.50	.....	.....	4.50	0.37	6.55		
Antimonial-lead¶.....	".....	70.55	21.72	.....	0.81	.....	.....	.....	.....	.....
Alloy.....	Hard bearing.....	98.00	.....	.....	.....	2.00	.....	.....	.....	.....
Antifriction.....	".....	98.75	.....	.....	.....	1.25	.....	.....	.....	.....
".....	Lead pipe *.....	97.96	0.45	1.56	0.10	.....	0.03	.....	.....	.....
".....	Shot.....	OU	.....	.....	.....	.....	.....	.....	.....	3.00		

* 20% Antimonial-lead. † Sodium. § Analysis of hard unrefined lead. ¶ Sperry.

at the same time be as hard as possible. Though it is difficult to satisfy these demands entirely, an alloy consisting of lead and antimony best answers the purpose. Antimony hardens lead, and if too much were used would render it brittle. The following alloys are now used as type metals:

TABLE 58.—*Composition of standard type metals*

Name	Lead, %	Antimony, %	Tin, %	Copper, %
Standard electrotype....	93.00	4.00	3.00	None
Standard linotype.....	83.00	12.00	5.00	"
Standard monotype.....	74.00	18.00	8.00	"
Standard stereotype.....	82.50	13.00	4.50	"
Standard type metal....	58.00	15.00	26.00	1.00
Ordinary linotype.....	82.00	13.00	5.00	None
Cheap linotype.....	85.00	11.00	3.50	"

Probably the greatest single use of lead alloys is for type metals, but the extensive use of type-setting machines favors the use of but one alloy. The modern tendency is against the individual printer setting his own type as in the olden days; his type is set for him by firms which specialize in that work, and in every large city there are firms which make a business of casting the type for the printers. Instead of each letter being an individual entity, the entire line is cast in the form of a flat piece of metal carrying on one edge the words which make up the line, hence the word "linotype." The printer sends his copy to the linotypers, and there it is set up in type, the linotyper furnishing the metal, but charges only for the work, the ownership of the type metal being vested in the linotyper. Obviously, after the type has been used, the metal cannot be thrown away, so it is returned to the linotyper. This has led to the development of the type-metal clearing house, generally managed by an independent firm, having an arrangement with the printers and linotypers on the one hand, and the metal producers on the other. The printers notify the clearing house when type has served its usefulness, and the scrap is collected and is re-melted in a furnace designed especially for the purpose, and is then run into suitably-

shaped ingots which are delivered to the linotypers as required. A record has to be kept of the weight of metal delivered by the different linotypers to the printers, so that the re-melted metal can be properly apportioned. After a while the composition of the metal will usually approximate that of the cheap linotype given in the foregoing table. Care has to be exercised by the re-melter to avoid contamination of the alloy with zinc, to which end it is advisable to remove any brass strips, called "leads" which may fall into the scrap type. Another source of zinc may be the zinc line-cuts so largely used for line drawings.

If the zinc becomes mixed with the melted metal it can be largely eliminated by fluxing with sal-ammoniac, scattering it on the surface of the metal, stirring, and then skimming and repeating this a number of times; but it is very difficult to remove the last traces in the type melting pot. The presence of oxide in the metal is also harmful, as it renders the metal "thick," and it will not flow and fill up the dies. When this happens the metal has to be deoxidized, and the best method is to use a stick of green wood, which is forced to the bottom of the molten metal and held there to allow the bubbles of steam to rise up through the metal. This will have to be repeated until the alloy becomes fluid, and may require 30 minutes or more. The surface of the metal should be fluxed with rosin, and the dross removed by means of a perforated ladle.

There is a constant loss of tin in the re-melting process, owing to the settling by gravitation of the heavier lead to the bottom of the bath of molten metal. The dross skimmings, therefore, will be higher in tin than the alloy, and as 3.50% of tin is about the minimum that should be permitted in the alloy, additions of tin must be made from time to time. Solder joints are often used for this purpose; the high-tin babbitt metal scrap should not be used because it would introduce copper which would render the metal sluggish. After the metal has made a few trips around the circuit from linotyper to printer, to re-melter, and back again, it is advisable to

make an analysis to keep control of the composition. Trouble is averted by careful attention to such details. New metal has to be added to the circuit at intervals; it is sold by the metal melter to the clearing house, and from there to the linotypers. The dross is returned to the melter at an agreed price.

Sometimes difficulties are encountered in casting the type, and the metal will then be blamed; it will be thought that it

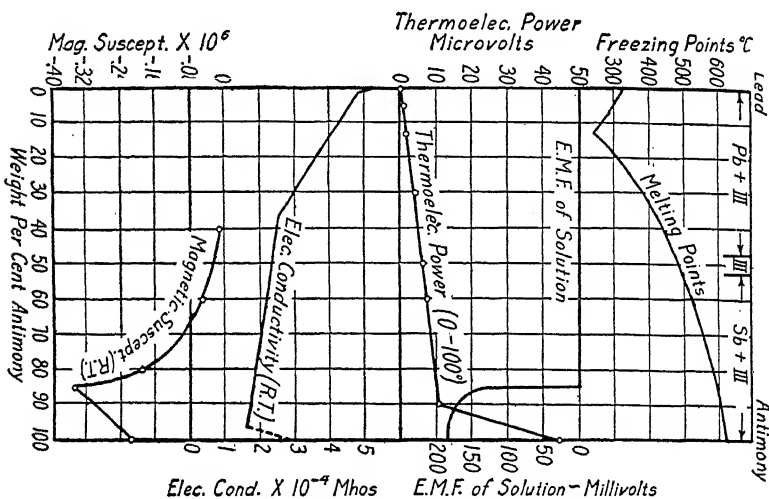


Figure 79.—Curve of lead-antimony alloys (Goutermann).

has become oxidized and thick, or that zinc or copper has got into it. If the re-melter has his analysis made at proper intervals, and watches the flow of the metal as it runs into the ingots, he will be sure of his mixture, and will usually find the defective type castings due to some defect in the heating of the melting pot on the linotype machine. When electricity is the heating medium, there may be some defect in the wiring which will cut off some of the heating element, and the type will come "cold shut." When this trouble is experienced at the machines it is always advisable to test the temperature of the metal during the progress of the work, and for this purpose the re-melter should have a pyrometer.

Figure 79 shows the freezing-point curve of lead-antimony alloys by Goutermann, and shows a eutectic in the neighborhood of 13% of antimony.

Shot-metal.—The mixture used in the manufacture of shot consists of lead and arsenic. The latter, as previously mentioned, possesses the property of hardening lead, the alloy being at the same time more fusible than pure lead. Shot, as is well known, is prepared by letting lead fall into water from an elevated place known as a “shot-tower”; and an addition of a very small quantity of arsenic helps its solidification and gives to the shot a more spherical shape.

On account of the poisonous properties of the arsenious vapors, certain precautions must be observed in preparing the alloy. The lead is first melted in a cast-iron pot provided with a well-fitting lid, and then covered with a layer of charcoal dust. Only after this is done should the arsenic be introduced. In many shot factories this precaution is omitted, which, however, deserves censure, as everything should be done to protect the workmen from the injurious effects of the vapors. If the metal is covered with a layer of charcoal dust, the vapors cannot reach the air as easily as when the bright metal is in direct contact with the air. White arsenic (arsenious oxide) is generally used, though in some cases red arsenic (realgar or red orpiment) is employed. Immediately after the introduction of the arsenic the mass is vigorously stirred with a wooden rod, and the pot is then covered with the lid, which is luted around the edges with moist clay. A strong fire is kept up to render the contents of the pot thinly-fluid. After about three hours the lid is removed, and the charcoal and oxides floating on the surface having been carefully skimmed off, the alloy is poured by means of ladles into molds. This alloy serves for the preparation of the actual shot lead, which is prepared by melting lead and adding a certain quantity of the alloy of lead and arsenic. It is in all cases preferable first to prepare the arsenical alloy in the manner prescribed, it being difficult otherwise to com-

bine the lead intimately and homogeneously with the comparatively small quantity of arsenic required for shot metal.

In this process, generally 1000 parts of lead are alloyed with 20 parts of arsenic, and equal parts of this alloy and of lead are subsequently melted together. For the direct preparation of the alloy of lead and arsenic for shot, 2.4 parts of arsenious oxide are used for 600 parts of refined lead, or 3 parts of arsenic to 700 parts of lead. As will be seen, the quantity of arsenic is exceedingly small, and should in no case exceed that actually required for hardening the lead and rendering it easy to cast. The quantity considered necessary for this varies in different countries; for instance, in England, 10 parts of arsenic are allowed for 1100 parts of lead; and in France, 3 to 8 parts are considered sufficient for 1000 parts of lead.

This variation in the proportions of arsenic used for hardening the lead is readily accounted for by the difference in the qualities of the lead used; the purer and softer the lead the greater the quantity of arsenic required. But under no circumstances should good shot metal contain more than from $\frac{1}{1000}$ to $\frac{10}{1000}$ (0.001 to 0.01%) of the weight of lead used. But too little or too much arsenic is injurious; if the lead contains too little, the resulting shot has the shape of tears, and the interior is frequently full of cavities, while with too much arsenic the drops are lenticular. Even with much experience it is fairly difficult to secure the right proportion at once, so it is advisable before melting together large quantities of lead and arsenic, to make tests with small quantities. From the shape of the shot obtained from these samples it can be readily judged whether the proportions are correct, or in what respect they have to be changed.

Many shot manufacturers, it would seem, vary the composition of the alloys used, as, besides lead and arsenic, other metals are frequently found in shot, especially antimony and copper, though the latter is only in exceedingly small quantities. The antimony content is, however, larger, in many cases up to 2% of the total weight, and from this it would

appear that the manufacturers endeavor to replace the arsenic by antimony.

Casting shot.—According to the old method, shot is prepared by allowing the molten metal to fall in drops from a tower of considerable height. This method is said to have originated with a plumber named Watts, at Bristol, England, who, about the year 1782, dreamed that he was out in a shower of rain, that the clouds rained lead instead of water; and the drops of lead were perfectly spherical. He determined to try the experiment, and, accordingly, poured some melted lead from the tower of St. Mary Redcliffe Church into some water below; the plan succeeded, and he sold the invention for a large sum of money.

For carrying out this process shot-towers and shot-wells have been constructed. At the top of the tower, molten lead is poured into a colander, and the drops are received into a vessel of water below. The surface of the lead becomes covered with a spongy crust of oxide called "cream," which is used to coat over the bottom of the colander to prevent the lead from running too rapidly through the holes, whereby they would form oblong spheroids instead of spheres. The colanders are hollow hemispheres of sheet iron. The holes in them differ according to the size of the shot, and they must be at a distance of at least three times the diameter of the shot from each other, otherwise it might happen that two or more drops of lead would, while falling down, unite to form one mass, which, of course, would be useless and have to be re-melted.

The water serving for the reception of the drops must be frequently changed to prevent it from becoming too hot. Some makers recommend pouring a layer of oil on the surface of the water, the shot retaining thereby its spherical shape better than when dropping directly into the water. To prevent the shot from losing its metallic appearance by oxidation when taken from the water, a small quantity (about 0.25%), of sodium sulphide is dissolved in this water. The drops falling into the water are at once coated with a thin

film of sulphide of lead of a lustrous, metallic, gray-black color, which is permanent even in moist air.

The formation of shot by centrifugal machines is a later process. The molten lead is poured in a thin stream upon a rapidly revolving metal disc, surrounded at some distance by a screen against which the shot is thrown. The moment the melted lead falls onto the metal disc it is divided into drops by the centrifugal force, the size of which depends on the rapidity with which the disc revolves. The drops are hurled off at a tangent from the disc and are stopped by the screen.

Sorting the shot.—Even with the most careful work it happens that drops of unequal size or cornered masses are found among the shot, and the latter, after being taken from the water and dried, must be sorted. This was formerly effected by hand in the following manner: A slab of polished iron is tilted at an angle, and the shot are placed along the upper part of the plate. The perfect shot roll rapidly in straight lines and fall into a bin, placed about a foot away from the bottom, while the misshapen shot, travel with a slower irregular motion, and fall without any bound into a bin placed immediately at the end of the incline. The perfect shot are then subjected to another sorting by passing them through sieves with holes exactly the same size as the apertures in the casting colanders.

The finished shot, which are now of dead silvery-white color, are polished and made dark in an iron barrel or rumble containing a quantity of powdered plumbago. They are then tied up in canvas bags and are ready for sale.

At the present time, shot are generally sorted by means of sorting drums consisting of inclined cylinders perforated with holes whose diameter corresponds to that of the shot. The forward motion of the shot in these drums is effected by means of an Archimedean screw.

Large shot are also frequently prepared by casting in molds like bullets, or by punching them from thin plates of the alloy. In both cases the resulting shot shows a seam which is removed by bringing the shot together with very fine quartz

sand into revolving drums. By the action of the sand the seams are ground off, and a perfectly spherical shape is imparted to the shot.

Alloys of lead and iron.—Lead, as previously stated, has no affinity for iron; it is impossible to form an alloy with them. A piece of lead thrown into a bath of molten iron becomes oxidized, or is separated and found at the bottom of the bath after the cast iron has been run out. As soon as the lead is introduced into the molten cast iron, the surface becomes agitated, even through the whole bath, and the cast iron seems more fluid. When thin or large pieces are to be cast, the founders, aware of this phenomenon, often throw some lead into the molten cast iron to prevent it from congealing too soon against the sides of the casting ladle.

This want of affinity of lead for iron, and iron for lead, is made use of for separating iron from other metals, such as silver, for instance. Thus, if lead is added in sufficient quantity to a fused alloy of cast iron and silver, it will combine with the silver, and the iron will float on the surface of the bath.

Alloys of lead and other metals.—Lead, as seen from the preceding sections, is much used in the preparation of alloys which have been already partly mentioned under the respective mixtures of metals. Lead is also frequently alloyed with cadmium and bismuth, and forms an important constituent of the so-called "soft solder." In speaking of these compounds, the lead alloys not yet mentioned will be referred to. Only type metal, shot metal, and certain antifriction metals can be considered as lead alloys—that is, alloys of which lead forms the greater portion.

CHAPTER XX

ALLOYS OF MERCURY AND OTHER METALS, OR AMALGAMS

MERCURY, or quicksilver, is the only metal which is liquid at an ordinary temperature. It solidifies at -40° F., forming a ductile, malleable mass, and boils at 662° F., forming a colorless vapor; it volatilizes, however, even at ordinary temperatures. With other metals it forms alloys which are called amalgams. According to Thomas Aquino and Libadius the term amalgam is derived from the Greek *μάλαγμα*, softening body; and according to other authorities, from the Arabic *algalams*. The properties of the amalgams vary very much according to the metals used. In most cases they are at first liquid and after some time acquire a crystallized form, the mercury in excess being thereby eliminated.

The amalgams offer an excellent means of studying the behavior of the metals toward one another, the examination being facilitated by the low temperature at which these combinations are formed. If a metal be dissolved in mercury, and the latter be present in excess, a crystalline combination will in a short time be observed to separate from the original liquid mass. This crystalline combination forms the actual amalgam, and is composed of proportions which can be expressed according to determined atomic weights, and can be readily obtained by removing the excess of mercury by pressure.

Many amalgams require considerable time to pass into the crystalline state, and are at first so soft or plastic that they can be kneaded in the hand like wax, but harden completely in time. They are especially adapted and much used for filling teeth.

Before the action of the galvanic current upon solutions of metals was known, amalgams were of great importance for gilding and silvering, which was effected by coating the article with the amalgam and volatilizing the mercury by heat, whereby the gold and silver remained behind as a coherent coating (fire-gilding).

Mercury unites readily with lead, zinc, tin, bismuth, cadmium, copper, gold, silver, magnesium, potassium, and sodium; while iron, nickel, cobalt, manganese, and platinum in the compact state combine with it with difficulty.

Though the amalgams are of considerable theoretical interest and of great importance for a general knowledge of alloys, only a limited number are used in the industries, which will be somewhat more closely described in the following:

Gold amalgam.—Gold and mercury alloy freely, and the amalgam can be prepared by the direct union of the two metals. If the gold to be used has been obtained by the chemical process (by the reduction of gold salts) it dissolves with difficulty in the mercury, it being in a finely divided state, and the finer particles are inclined to float on the surface of the mercury. If, however, the gold is reduced in the form of larger crystals, the solution takes place in a comparatively short time. Such small gold crystals can be readily obtained by dissolving gold chloride in amyl-alcohol and heating the solution to boiling, whereby the gold is separated in the form of very small, lustrous crystals.

In recovering gold from auriferous ores and gravels, large quantities of amalgam are formed, and by subsequent heating in iron retorts the combination is destroyed, the mercury being distilled or volatilized, and condensed, while the gold remains behind. Gold forms with mercury a combination of the formula Au_4Hg , showing great tendency toward crystallization, which, in preparing the amalgam, must be prevented as much as possible, it being difficult to apply a crystalline amalgam to the articles to be gilded.

An amalgam suitable for fire-gilding is best prepared as follows: Heat the gold to be alloyed to a red heat in a

graphite crucible, rubbed inside with chalk to prevent adhesion. It is not necessary to use chemically pure gold, but it should be at least 22 carat ($\frac{916}{1000}$) fine, and preferably alloyed with silver instead of copper. Gold amalgam containing copper becomes stone hard in a short time, and a small amount of it impairs its uniform application to the metals to be gilded. It is best to use the gold in the form of thin sheets, which is cut into small pieces by scissors, and placed in the crucible. When the gold is heated to a red heat, introduce about an eighth or ninth part of the weight of the gold of mercury previously heated to boiling. Stir constantly with an iron rod, and after a few minutes remove the crucible from the fire. If the finished amalgam were allowed to cool in the crucible it would become strongly crystalline, and would be unsuitable for fire-gilding. To prevent this, it is at once poured into a larger vessel cooled on the outside by water. By keeping this amalgam for some time crystallization takes place, nevertheless, the amalgam separating from the mercury in excess, and it is therefore advisable to prepare it fresh a short time before use. Crystalline amalgam can be restored by heating it in a crucible with an excess of mercury.

Gold amalgam containing silver gives a green gilding, and as this color is frequently desired, argentiferous gold is used in preparing the amalgam. The color may be intensified by the application of a mass consisting of 17 parts of niter, 14 parts of sal-ammoniac, and 2 parts of alum, and heating.

In preparing the amalgam, as well as in using it for gilding, a wind furnace connected with a high chimney should be used, otherwise the vapors evolved from the mercury exert an injurious effect upon the workmen.

A native gold amalgam, with the formula Au_2Hg_2 containing 39.02 to 41.63% gold and 60.98 to 58.37% mercury has been found in California.

Silver amalgam.—The properties of silver amalgam are nearly the same in most respects as those of gold amalgam, it having, however, a still greater tendency towards crystallization. Only pure silver can be used for its preparation,

copper producing the same injurious effect as in gold amalgam. Silver amalgam is best prepared by using pulverulent silver obtained by the reduction of silver solution. It may be prepared by putting a solution of silver nitrate in 10 to 15 parts of water into a bottle, adding a few small pieces of sheet zinc, and shaking a few minutes. The silver separating in the form of a very fine black-gray powder need only be washed and dried to be suitable for the preparation of amalgam. This finely divided powder can be directly dissolved in the mercury, though it requires some time. The object is more quickly attained by heating the mercury nearly to boiling in a crucible, then throwing in the pulverulent silver, and quickly combining the mass by stirring with an iron rod.

Silver amalgam can also be prepared without the use of heat, it being only necessary to compound a concentrated solution of nitrate of silver (1 part of nitrate of silver in 3 of distilled water) with four times the quantity of mercury and combine the liquids by shaking. The silver is reduced from the nitrate by the mercury and dissolves immediately in the excess of it. If the amalgam is to be used for fire-silvering, the presence of the small quantity of nitrate of mercury adhering to it is of no consequence, and it can be at once applied.

Fire-gilding, as well as fire-silvering, is always effected with a pure amalgam—that is, such as is freed as much as possible from an excess of mercury. For this purpose the amalgam is tied in a bag of strong chamois leather or close cotton cloth, and subjected to a gradually increasing pressure, whereby the mercury is forced through the pores of the cloth, while the amalgam remains in the bag. The pressed-out mercury contains a considerable quantity of gold or silver in solution, and is used in the preparation of fresh amalgam.

Fire-gilding as well as silvering is, of course, only applicable to articles of metals, which, without melting, will stand a temperature near that of the boiling point of mercury. As the amalgam only adheres to absolutely bright metals, the articles before gilding are subjected to preparatory treatment,

whereby they are heated, and the grease, dust, etc., adhering to the surface are burned, and the metal becomes covered with a layer of oxide. The articles are then dipped into a mixture of 3 parts nitric acid and 1 part sulphuric acid, whereby the oxide is rapidly dissolved and the metal acquires a bright surface. Articles to be heavily gilded must remain in the acid mixture for some time, a rougher surface being required for the adhesion of a larger quantity of amalgam.

The pickled articles are then rinsed in water without touching them with the hands, and, to prevent oxidation, they are placed in water until they are to be amalgamated, which consists in covering the bright articles with a layer of metallic mercury. This so-called amalgamating water is prepared by dissolving 100 parts by weight of mercury in 110 parts of strong nitric acid, and 25 parts of water. This amalgamating water is applied to the metals by means of a brush of fine brass wire. By the action of the metal upon the mercury salt the latter is reduced to metallic mercury in the form of very small drops, whereby the articles acquire a white color.

The articles being thoroughly amalgamated, the amalgam is quickly and uniformly applied with a stiff scratch-brush, and the articles are placed on glowing coals, whereby the mercury vaporizes while the gold or silver remains behind in a coherent layer. While heating, the articles must, however, be frequently taken out, and defective places coated with amalgam. This process is very injurious to health; the fumes of the mercury volatilized by the heat being readily absorbed by the pores of the skin, notwithstanding the greatest care; and those who escape for a time are constantly liable to salivation from its effects. Though fire-gilding is the most durable, it is being superseded by electroplating.

Many articles are not finished by one gilding, and have to be subjected to the same process twice, and frequently three times, whereby the layer of gold becomes thicker. By suitable treatment during the heating, and by burning off the so-called gilder's wax, various shades can be given to the

gilding. But these operations belong to another branch of industry not pertinent to this volume.

Copper amalgam.—On account of its peculiar properties, copper amalgam finds a fairly extensive use in several branches of industry, an amalgam of copper, tin, lead, and antimony serving in the manufacture of axle bearings. It crystallizes with great ease, and on solidifying becomes so hard that it can be polished like gold. It can also be worked under the hammer and between rolls, also stamped; and retains its metallic luster for some time on exposure to the air, but tarnishes quickly and turns black on being brought in contact with air containing sulphuretted hydrogen. A peculiar property of amalgam of copper is that it becomes soft on being placed in boiling, and so flexible that it can be used for molding the most delicate articles. In a few hours it again solidifies to a fine-grained mass which is quite malleable.

Copper amalgam, on account of its peculiar properties, was formerly recommended for filling teeth, but is no longer used for that purpose, there being other amalgams just as suitable and free from copper. An important application of copper amalgam is for cementing metal, it being only necessary to apply it to the metals to be cemented, which must be bright and previously heated to from 176 to 194° F., and press them together; they will be joined as tightly as if soldered.

Many directions have been given for preparing copper amalgam, but it is effected with the greatest ease as follows: Place strips of zinc in a solution of copper sulphate and shake well. The copper thus obtained in the form of a delicate powder is washed, and, while still moist, treated in a rubbing-dish with a solution of mercurous nitrate. Hot water is then poured over the copper, the dish being kept warm, and the mercury is added. The contents of the dish are then kneaded with a pestle until the pulverulent copper combines with the mercury to a plastic mass; the longer the kneading is continued the more homogeneous it will be. The best proportions to use are 3 parts of copper and 7 parts of mercury.

When the amalgam has the proper consistence, the water is poured off and the soft amalgam is molded in the shape desired. For the purpose of cementing it is best to roll it into small cylinders about $\frac{1}{8}$ inch in diameter and $\frac{3}{4}$ to $1\frac{1}{2}$ inches long.

A composition of 25 parts of copper in fine powder, obtained by precipitation from solutions of the oxide by hydrogen, or of the sulphate by zinc, washed with sulphuric acid, and amalgamated with 7 parts of mercury, after being well washed and dried, is moderately hard, takes a good polish, and makes a fine solder for low temperatures. It will adhere to glass.

An imitation of gold, known as "Vienna metallic cement," which, on account of its golden-yellow color and property for taking a fine polish, is suitable for the manufacture of cheap jewelry, consists of 86.4 parts of copper and 13.6 parts of mercury. The color of the alloy being, however, very easily affected by sulphuretted hydrogen, it is best to provide the articles with a thin coating of pure gold by the galvanic method.

Dronier's malleable bronze is made by adding 1% of mercury to the tin when hot, and this amalgam is carefully introduced into the molten copper.

Tin amalgam.—This amalgam was formerly of much greater importance for the manufacture of mirrors than at present, when mirrors coated with a thin layer of silver surpass those coated with amalgam in beauty and cheapness. The great affinity of tin for mercury renders easy the preparation of the amalgam, all that is necessary being to combine the tin—the best in the form of fine shavings or foil—with the mercury. According to the quantity of mercury rubbed together with the tin, an amalgam solidifying in a shorter or longer time is obtained.

Tin amalgam for filling teeth is prepared by intimately rubbing together 1 part of tin with 4 parts of mercury, removing the excess of mercury by pressing in a chamois bag, and

kneading or rubbing for some time. A plastic mass results, which hardens in a few days.

The amalgam which serves for silvering mirrors is a complete saturation of the two metals. It is, however, not prepared by itself, but directly on the plate of glass which is to form the mirror. The operation is as follows: The glass plate having been thoroughly cleansed from all grease and dirt with putty-powder and wood ash, a sheet of tin foil of larger dimensions than the plate to be silvered is laid smoothly on the silvering table. A small quantity of mercury is then poured upon it and uniformly distributed by means of a fine woolen cloth. When the surface is uniformly covered, more mercury is added so as to make a height of 2 or 3 lines; the coating of oxide is removed with a wooden rod and a brilliant surface results. The glass is then pushed slowly forward from the side with the longest edge foremost, and is dipped below the surface of the mercury to exclude the air completely. In this way the glass is brought into contact with the metals and a brilliant surface is produced. The plate may now be said to be floating on a bed of mercury. To get rid of the excess of metal, the mirror is loaded with weights and the table inclined 10 to 12 degrees, when the excess of mercury drains off. A further portion is eliminated by setting the plate up on edge, and in the course of three or four weeks a dry, permanent coating of tin amalgam is left upon the plate.

If curved glass plates are to be converted into mirrors, the amalgam is prepared alone, and after spreading it as uniformly as possible upon the glass, the latter is heated until the amalgam melts.

This method of silvering has many objections: The mercury vapor is poisonous; the plates are liable to fracture from the heavy load placed upon them; and when set up on edge drops of mercury sometimes trickle down, carrying the amalgam with them, thus rendering it necessary to re-silver the whole mirror. Moreover, the amalgam is liable to spoil by crystallization during transportation. For these reasons

this process has been almost entirely abandoned, and that of silvering by precipitation substituted.

Amalgam for coating rubbers of electric machines.—This amalgam, known as Kienmayer's, consists of 1 part zinc, 1 part tin, and 2 parts mercury. It is prepared by placing the metals in the form of fine shavings free from oxide into a preheated iron mortar, and rubbing it with the mercury to a homogeneous mass. The amalgam has a tendency to become crystalline, even if kept in well-stoppered glass vessels, but it can be readily pulverized, and if mixed with a very small quantity of tallow gives excellent service. By this method, the disadvantage of the otherwise unavoidable melting of the solid metals is avoided.

Singer's amalgam for the same purpose consists of 1 part tin, 2 parts zinc, and $3\frac{1}{2}$ to 6 parts mercury. Böttger melted in an iron spoon 2 parts of zinc, and carefully added, with constant stirring, 1 part of mercury.

Musiv silver.—This is a combination of 3 parts tin, 3 parts bismuth, and $1\frac{1}{2}$ parts mercury; and serves for the spurious silvering of brass and copper, the amalgam mixed with 6 parts bone-ash being applied by rubbing the articles with it. For silvering pasteboard, wood, paper, etc., the mass is triturated with white of egg, gum solution, glue water, or varnish, and applied to the articles.

Amalgam for tinning.—Small articles of iron, pins, etc., may be tinned by pickling them in an acid, dipping in tin amalgam made liquid by means of hot water, blanching, washing, drying with coarse bran, and polishing.

Zinc amalgam.—Zinc unites with mercury at the ordinary temperature, but more readily at a higher one. Triturate 1 part of zinc filings, 4 parts of mercuric chloride, and 2 parts of water, adding a few drops of mercury, or, mix 2 parts of mercury with 2 parts of zinc melted in an iron spoon, stirring constantly with a clay rod. The very brittle amalgam is powdered, triturated with tallow, and may be used for coating rubbers of electric machines.

Zinc amalgam is electrolytically prepared by connecting

by means of a wire the zinc cylinder of a Daniell cell with a small quantity of mercury covered by a zinc sulphate solution, a zinc wire serving as anode of the battery dipping into the solution.

For the amalgamation of zinc for voltaic cells, brush the zinc with ammonium zinc chloride at 450 to 500° F., and then apply the mercury, when complete combination will take place immediately.

The zinc may also be pickled in sulphuric acid, and the mercury applied with a metallic scratch-brush dipped in dilute sulphuric acid.

The zinc elements may also be immersed in a fluid prepared by dissolving 7 oz. of mercury in 35 oz. of aqua regia (3 parts hydrochloric and 1 part nitric acids) and 39 oz. of hydrochloric acid. With about 1 quart of this fluid 150 elements can be amalgamated.

Spurious gilding of copper by the formation of brass is produced by boiling the copper article in a mixture of tartaric acid, hydrochloric acid, and zinc amalgam (1 part zinc and 12 parts mercury).

Cadmium amalgam.—Cadmium readily combines with mercury to form an amalgam which easily becomes crystalline. For the preparation of the actual cadmium amalgam, whose composition is Cd_5Hg_8 , proceed in the same manner as already described for other amalgams. Heat the mercury nearly to boiling in a crucible, and introduce the cadmium in the form of thin sheet. Cadmium amalgam remains soft for some time, and becomes crystalline only after a considerable period. The mass obtained by heating is, therefore, allowed to stand in the crucible until the excess of mercury separates out; or it can be separated in the ordinary manner by squeezing in a chamois bag.

Pure cadmium amalgam forms a tin-white or silver-white mass which softens on being moderately heated, and can be kneaded like wax. It is used for filling teeth, either alone or compounded with other metals, which make it still better for the purpose. An addition of tin or bismuth makes it more

pliable in the heat, and for this reason the mixture used for filling teeth is at present frequently composed of amalgams containing several metals. A few such compositions are given below. Those containing lead are, however, not recommended, as lead has poisonous properties, and is attacked by organic acids, even when in the form of an amalgam:

Dental amalgams

Cadmium.....	25.99	21.74	1	1 to 2	3
Mercury.....	74.01	78.26			
Tin.....	.....	.....	2	2	4
Lead.....	.....	.....	.....	7 to 8	15

The first amalgam is well adapted for filling teeth, it acquiring in time such hardness that it can be worked with the lathe or file, and, of course, becomes hard in the mouth. Cadmium amalgams being very ductile, can, moreover, be used for many other purposes. An amalgam of equal parts of cadmium and mercury is extremely plastic, and can be stretched under the hammer like pure gold. It is silver-white and constant in the air.

Evans' metallic cement.—This alloy is obtained by dissolving a cadmium amalgam consisting of 25.99 parts of cadmium and 74.01 parts of mercury in an excess of mercury, slightly pressing the solution in a chamois bag and thoroughly kneading. By kneading, especially if the amalgam be previously heated to about 97° F., this cement is rendered very plastic, and like softened wax can be wrought into any desired form. On cooling it acquires considerable hardness, which is, however, not equal to that of pure cadmium amalgam.

Amalgams of the fusible alloys.—The fusible alloys already mentioned, in discussing the alloys of cadmium and bismuth, possess the property of melting in an amalgamated state at a still lower temperature than by themselves. By adding a suitable quantity of mercury to them, they can be converted into masses well adapted for filling teeth or for cementing metals.

Amalgam of Lipowitz's metal.—This amalgam is prepared as follows: Melt in a dish 3 parts of cadmium, 4 parts of tin, 15 parts of bismuth, and 8 parts of lead, and add 2 parts of mercury to the melted alloy, previously heated to about 212° F. Amalgamation takes place readily and smoothly. After the introduction of the mercury, the dish is immediately taken from the fire and the liquid mass stirred until it solidifies. While Lipowitz's alloy becomes soft at 140° F. and melts at 158° F., the amalgam melts at 143.5° F. It is suitable for the production of direct impressions of leaves and other delicate parts of plants, which, as regards sharpness, are equal to the best plaster of Paris casts; and, on account of the silver-white color, fine luster, and permanency of the amalgam, present a very neat appearance. The amalgam can also be used for the manufacture of small hollow statuettes and busts, which can be readily gilt or bronzed by the galvanic process.

The manufacture of small statuettes is readily effected by preparing a hollow mold of plaster of Paris, and, after uniformly heating it to 140° F., pouring in the molten amalgam. The mold is then swung to and fro, this being continued until the amalgam is solidified. After cooling, the mold is taken apart, and the seams are trimmed with a sharp knife. Some experience being required to swing the mold so that all parts are uniformly moistened with the amalgam, it may happen that defective casts are obtained at first; in such case, the amalgam is simply re-melted and the operation repeated. With some skill the operator will soon succeed in applying a uniform layer to the sides of the mold and preparing casts with very thin sides. The operation may also be modified by placing the mold upon a rapidly revolving disc and pouring in the molten amalgam in a thin stream. By the centrifugal force developed the molten metal is hurled against the sides of the mold, and in this manner statuettes of considerable size can be cast.

Iron amalgam.—Iron and mercury do not unite directly, and can only be combined by means of a third metal, though it is sometimes doubtful whether an actual amalgam is formed.

According to Böttger, the amalgam may be prepared by triturating 1 part of finely divided iron with 2 parts of mercuric chloride and 2 parts of water, and adding a few drops of mercury.

Gulielmo triturated in a porcelain dish $4\frac{1}{2}$ parts of pulverized ferrous sulphate and 1 part of pulverized zinc with 12 parts of water at 140 to 167° F., and freed the iron amalgam, which, after some time, is formed by washing from the rest.

According to Joule, a crystalline mass of lustrous iron amalgam, especially beautiful if composed of 100 parts of mercury and 47.5 parts of iron, is formed by connecting by means of wire the zinc cylinder of a Daniell cell with a small quantity of mercury in a ferrous sulphate solution, an iron wire dipping into the latter serving as anode of the battery. According to the duration and intensity of the current the amalgams are solid or liquid, crystalline, and with metallic luster with different amounts of iron (0.143 to 103.2 parts iron to 100 parts mercury). The amalgams are magnetic, and when subjected to violent shocks the iron is superficially separated in pulverulent form. When heated to the boiling point of mercury, ferric oxide remains behind, sparks being emitted. When submerged under water, the amalgam in a few days becomes covered with rust, and, on shaking the vessel, is almost immediately disintegrated, the iron floating in the form of a black powder upon the mercury.

To be uniformly gilded with gold amalgam, iron particles are frequently first coated with a layer of mercury by boiling them, after thorough cleaning, in a porcelain or clay vessel in a mixture of 12 parts of mercury, 1 part of zinc, 2 parts of ferrous sulphate, 12 parts of water, and $1\frac{1}{2}$ parts of hydrochloric acid. A mirror-bright surface is thus obtained to which the gold amalgam can be uniformly applied.

Bismuth amalgam.—By introducing mercury into molten bismuth, a combination of the two metals is readily effected. The resulting amalgam being very thinly-fluid, it can be advantageously used for filling out very delicate molds. Other amalgams are also rendered more thinly-fluid by an addition

of bismuth amalgam, a few examples of which have already been given under cadmium amalgams, and such combinations, being cheaper than pure bismuth amalgam, are frequently used.

Bismuth amalgam can be used for nearly all purposes for which cadmium amalgams are employed. On account of their luster, which is at least equal to that of silver, they are preferred for certain purposes, such as for silvering glass globes and the preparation of anatomical specimens.

Amalgams for silvering glass globes, etc.—These can be readily silvered by either of the following compositions (parts):

Formulas for silvering amalgams

Bismuth.....	2	2	2
Lead.....	2	2	2
Tin.....	2	2	2
Mercury.....	2	4	18

First melt the lead and tin, and then add the bismuth. After removing the dross, pour the mercury into the compound and stir vigorously. Leaves of Dutch gold are sometimes introduced into the mixtures according to the color to be imparted to the globes. For silvering the globes, heat them carefully to the melting point of the amalgam; then pour a small quantity of the amalgam into the cavity of the globe, and swing it to and fro until its entire surface appears covered.

Amalgam of bismuth for anatomical preparations.—Colored wax was formerly exclusively used by anatomists for injecting vessels. A bismuth amalgam, being of a silvery-white color, is, however, preferable, and by becoming hard on cooling contributes essentially to the solidity of the preparation. The amalgam used for the purpose melts at 169° F. and remains liquid at 140° F., the latter property rendering its use especially suitable for larger preparations. It is composed of 10 parts bismuth, 3.2 parts lead, 3.5 parts tin, and 2 parts mercury. For use, heat the amalgam in a

dish in a water-bath to 212° F., which ensures it being forced by the injection pump into the finest indentations of the vessels.

Metallic pencils may be prepared from an alloy of 70 parts lead, 90 parts bismuth, and 8 parts mercury. The lead and bismuth are first melted, and the metal is allowed to cool somewhat when the mercury is added, stirring constantly. If necessary, the whole is again heated and the alloy cast in molds.

Pholin's silver-like alloy consists of 19.23% bismuth, 76.90% tin, 3.84% copper, and a trace of mercury.

Sodium amalgam.—This amalgam is not used alone, as it decomposes quickly on exposure to the air into caustic soda and mercury. It can, however, be used in the preparation of many amalgams which cannot be made by the direct method. For instance, by bringing a sodium amalgam into contact with a solution of metallic chloride, the respective metal is generally separated from the chlorine combination by the sodium, and the moment it is liberated it unites with the mercury to form an amalgam, while the sodium combines with the chlorine. The presence of a very small quantity of sodium amalgam exerts, moreover, a very favorable effect upon the formation of amalgams; and by its use in the process of amalgamation of gold and silver in ores considerable time is saved and the amalgamation becomes more complete. Platinum and mercury hardly amalgamate, but with sodium amalgam, platinum is readily amalgamated.

Sodium and mercury unite at the ordinary temperature to form an amalgam, which, in the proportion of 1 part sodium to 80 parts or more mercury, is soft to liquid, but solid with a larger sodium content. For the preparation of an amalgam as rich in sodium as possible, 35 oz. of mercury is heated in an iron dish to 300° F., and 1 oz. of sodium in coarser pieces is introduced in rapid succession, the sodium pieces being pressed beneath the mercury by means of a rod. Vigorous heating accompanied by sputtering or sparking takes place, mercury vapors being evolved at the same time. After cool-

ing, the amalgam congeals to a solid brittle mass, which must be protected from moisture.

For the preparation of the amalgam Rosenfeld* used a crucible with a perforated lid. The aperture in the lid was closed by a well-fitting cork, and in the latter was a pointed wire reaching to the bottom of the crucible. The sodium in one piece was fastened to the wire and dipped into a mixture of 1 part amyl-alcohol and 9 parts petroleum. When the sodium acquired a pure silver-white color, it was taken from the fluid and placed into the crucible containing the mercury. The combination of the two metals took place instantaneously with the emission of a peculiar hissing noise and sparking. However, as the crucible at the moment of reaction was closed with the lid, little mercury vapor passed into the air.

Potassium amalgam is obtained by the introduction of potassium into heated mercury, the air being excluded as much as possible, or by pressing the freshly cut surface of the metal upon mercury, vigorous heating taking place thereby, and an amalgam is formed which become rigid if it contains over 3% potassium.

By introducing 3% of sodium amalgam into potash lye, a crystallizing combination Hg_{24}K_2 is formed in the shape of hard lustrous cubes with octahedron and dodecahedron faces. When heated to 824°F. , the cubes leave behind crystalline HgK_2 , which spontaneously ignites in the air. The amalgam decomposes slowly in moist air and under water, and, like sodium amalgam, may be used for amalgamating iron and platinum, as well as in the amalgamation of silver and gold ores, the amalgam taking up gold and silver with greater ease than mercury.

Nickel amalgam is formed in the shape of a plastic mass by rubbing together concentrated nickel chloride solution and an amalgam formed from 1 part sodium and 99 parts mercury, and treating the nickel amalgam thus formed with water until the latter runs off clear. It may also be formed by the addition of mercury to nickel sulphate solution.

* Berchite der chemischen Gesellschaft, vol. 24, page 1659.

Platinum amalgam.—A thickly-fluid lead-gray mass is obtained by triturating spongy platinum with heated mercury, or by introducing sodium amalgam into a platinic chloride solution.

Joule obtained an amalgam of a doughy consistence by allowing mercury to remain for a longer time in platinic chloride solution. After being pressed, the amalgam contained Hg_2Pt .

By boiling thin platinum sheet in mercury, with the air excluded, the former is attacked by the latter, and the greater portion of the platinum appears to be suspended in the form of a fine, black dust in the mercury. If this dust is forced upward by a current of air, and the mercury is isolated, only an inconsiderable quantity of platinum remains behind.

Mackenzie's amalgam.—This amalgam, which is solid at an ordinary temperature, and becomes liquid by simple friction, may be prepared as follows: Melt 2 parts of bismuth and 4 parts of lead in separate crucibles, then throw the molten metals into two other crucibles, each containing 1 part of mercury. When cold, these alloys or amalgams are solid, but will melt when rubbed against one another.

CHAPTER XXI

ALLOYS OF THE PRECIOUS METALS *

THIS chapter is devoted to gold, silver, and platinum, which are the "common" precious metals, if they may be so termed. The "rare" precious metals are those of the platinum group, but only call for passing mention here.

GOLD ALLOYS

Gold has been known and used by every nation, uncivilized and civilized, from the earliest period down to our time. It is found among the old Egyptian monuments, and semi-barbarous nations have used it in the form of dust as the principal medium of exchange, the instrument of association. When America was discovered by Columbus, gold was well known to its inhabitants; the Chinese have used it from time immemorial; the Medes and Persians were remarkable, even more than other Asiatics, for their love of gold; jewels of costly description were employed to indicate the rank of the wearer, and this custom is still continued in the East at the present time. To show the sacred value the ancient Egyptians placed on gold, it was represented by a circle with a dot in the middle, this circle among that nation being the symbol of divinity and perfection.

Gold is one of the metals which most readily enter into combination with other metals; but this property is without importance when we consider the lack of utility of the majority of the compounds, and the necessity of not debasing its value nor impairing its properties. Moreover, it is certain that excepting its alloys with copper, silver, iron, and platinum, gold loses part of its ductility, resistance, and cohesion,

* Part of the text on gold and silver alloys was prepared by Geo. S. Overton.

when it is combined with other metals such as zinc, tin, lead, etc. Therefore, it is entirely useless to experiment on those alloys where gold loses not only a part of its monetary value, but also those valuable properties which make it a "noble" metal.

The principal alloys of gold used at the present time are those with copper or silver; or, in rare cases, with both these metals.

Gold and copper have great mutual affinity, and may be alloyed in all proportions. The alloys are harder and more fusible than gold alone. Copper diminishes the ductility of gold when it enters into the combination in a proportion over 10 to 12%. The specific gravity of an alloy of gold and copper is less than the average of the two metals. The color of the alloy varies between dark yellow and red, according to the quantity of copper. Pure copper must be used in the preparation of the alloys, as the impure metal alters the malleability of gold and may render it brittle.

Gold and silver may be easily mixed together, but do not appear to form true combinations. These compounds are more fusible than gold, and are generally greenish-white, more ductile, harder, more sonorous and elastic than gold or silver considered singly. About 5% of silver is sufficient to modify the color of gold. Silver, like copper, increases the firmness of gold, and on that account it is employed at various degrees of fineness for jewelry. These alloys are known by jewelers under the names of green gold and white gold, according to the proportion of silver.

As previously mentioned, the alloys of gold with other metals are of no practical utility, and need only be briefly referred to. Gold alloyed with iron forms pale gray masses, brittle, and somewhat magnetic. An alloy holding, say 16% of iron is employed in jewelry under the name of gray gold.

Lead shows a peculiar behavior towards gold. Both metals are very soft and ductile, but when alloyed they form an exceedingly brittle metal of a pale yellow color, strongly crystalline, and hard as glass. According to Berthier, one-

half of one-thousandth (0.0005%) of lead alloyed to gold is sufficient to render the latter metal entirely brittle and without ductility.

Arsenic or antimony alloyed with gold gives a brittle and very crystalline alloy of a white or gray color. Accidental admixtures of either of these two metals can, however, be removed in a simple manner, it only being necessary to keep the metal in a molten condition for some time, whereby they volatilize, and the pure gold remains behind.

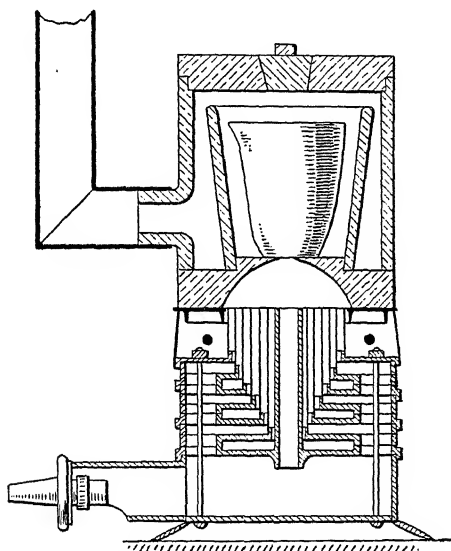


Figure 80.—Small gas or kerosene-fired jeweler's furnace.

Equipment for melting gold and silver alloys.—All jewelry shops and factories are equipped with a blower or fan system for gas furnaces used in melting gold and silver, also copper and the other low-grade metals, such as brass, cadmium, zinc, etc. All equipment can be purchased from jewelers' supply and outfitting houses.

A small crucible furnace suitable for jewelers is shown in figure 80. It will hold crucibles up to 4 by 3½ inches, containing about 6 lb. of metal when filled. With a ½-inch gas pipe supplying about 50 cubic feet per hour, it will rapidly

melt gold or silver. The cover of the furnace can be removed easily by means of a special tongs provided for the purpose. The graphite cylinder surrounding the crucible must always be placed with the narrow end downwards, as shown. Its purpose is to carry the flame upward to the top of the crucible, then by striking the furnace cover it is deflected downward, outside the cylinder, and escapes from the furnace by means of the flue on the side. Thus the heating value of the flame is utilized to the fullest extent.

The gas supply can be varied by turning the screw nozzle at the end of the mixing chamber, where the gas connection is made, and either an oxidizing or reducing flame can be obtained. As the gas enters it draws in air in the usual manner with gas-burners, and the mixed gas and air escaping from the other end of the burner forms a number of circular, concentric flames, as shown on figure 81. The alternate tubes only carry gas, the ones between draw up air, which both separates the rings of flame, and supplies air for perfect combustion. By this arrangement, a very hot flame is obtained.

Melting gold, silver, copper, and other metals used in alloying.—Pure gold and fine silver come from the United States Assay Office in bars. These are rolled down to about the thickness of a 10-cent piece, cut into not larger than 1-inch squares for convenience in placing in crucibles, and also for better mixing in melting. The refiners also sell the two metals in a granulated sponge form, which is preferred by some melters. Granulation consists in pouring the molten metal into a large tub or pan of water, which is rapidly stirred with a long stick (broom handle). The higher the pouring elevation the better the result. Graphite crucibles are used, and in all gold alloys a flux of 66% powdered willow charcoal and 33% powdered sal-ammoniac is used. The silver and copper are put in first, and then about one tablespoonful of the flux, and shaken thoroughly. The gold is placed on top. As soon as the whole is melted, stir well, using an iron, carbon, or charcoal rod. Never leave any metal in the crucible any

longer than to melt well, and never pour any metal any hotter than necessary. This, of course, means that all molten metals, to get best results, should be poured at the instant just before commencing to settle or solidify. This is particularly true in the case of silver, also the higher grades of gold—18, 20, or 22 carat.

Ingots molds should be oiled and warmed so that the hand can barely touch them for an instant. After removing the bar or plate from the mold it should be allowed to cool, and the first few passes through the rolls must be as heavy as possible to close up the grain in the center and prevent cracking. Some melters hammer the bar well before rolling. The stock must be annealed during the process in proportion to the hardness of the alloy.

In making white-gold alloys, the stock, however, should be rolled one-third of its original thickness before annealing. After annealing, the stock, when nearly cool, is plunged into pickle* and well rinsed in clear cold water and wiped dry. In melting silver, it has generally been found advantageous to throw in a few crystals of borax (boracic acid) just at the melting point. Some melters also prefer clay crucibles instead of graphite for silver. In this case, it is well to anneal the crucible first, after rubbing the inside thoroughly with borax powder.

When it is desired to produce very tough gold, use as flux a tablespoonful of charcoal and one of sal-ammoniac, adding it to the gold just before melting; the sal-ammoniac burning away while toughening the gold. The employment of this mixture of sal-ammoniac will bring the ingots of gold up bright and clear; it will also prevent them from splitting or cracking when rolled and in subsequent working.

* Sulphuric acid pickle is made by pouring one part of acid into a crock or lead jar containing 10 parts of water. This pickle is generally used for all carat grades, but some of the shops making only 14 carat should use a nitric acid pickle, in which one part of nitric to 10 or 15 parts of water are used. On this latter work the nitric pickle boils out work whiter and cleaner. It is a little too strong for anything under 14 carat, as too much of the alloy is attacked.

NOTE.—Never pour water into acid; always pour acid into water.

In re-melting scrap gold from the workshop, and old gold, care should be taken that they are not too much contaminated by solder and are free from organic matter, wax, etc. The solder used in soldering gold-ware contains tin, lead, bismuth, and sometimes zinc; and the presence of these metals has an injurious effect upon the ductility of the gold. It is best to separate much contaminated gold from the foreign metals

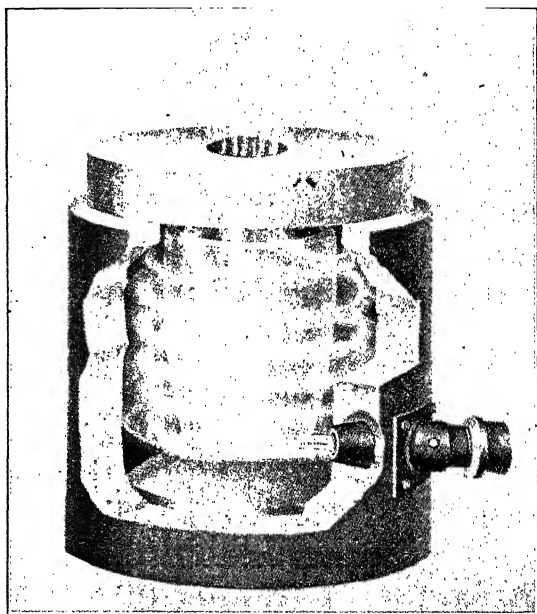


Figure 81.—Path of flame in a gas or oil-fired furnace.

by the wet process, and alloy the resulting chemically pure gold.

In most countries there are legally fixed standards for gold alloys, they generally consisting of so many carats to the unit, the pound, or half pound being divided into 24 carats, each of which contains 12 grains. What is termed 18-carat gold is a unit of 24 carats of alloy containing 18 carats of gold and 6 of copper. Since the introduction of the decimal system the fineness of gold alloys has been determined by thousandths, the fineness of the alloys being officially expressed

in this manner. Notwithstanding the simplicity of the system, many manufacturers still hold to the old method and calculate according to carats and grains. To save calculation the conversion of carats and grains into thousandths is given in table 59:

TABLE 59.—*Carat equivalents in thousandths*

Grains	Grains	Carats	Carats
1 = .. 3.47	10 = .. 34.73	7 = .. 291.666	16 = .. 666.667
2 = .. 6.95	11 = .. 38.19	8 = .. 333.333	17 = .. 707.333
3 = .. 10.42	12 = .. 41.67	9 = .. 374.999	18 = .. 750.000
4 = .. 13.89	Carats	10 = .. 416.667	19 = .. 791.666
5 = .. 17.36	1 = .. 41.667	11 = .. 458.630	20 = .. 833.333
6 = .. 20.84	2 = .. 83.334	12 = .. 500.000	21 = .. 874.999
7 = .. 24.31	3 = .. 125.001	13 = .. 541.667	22 = .. 916.666
8 = .. 27.78	4 = .. 166.667	14 = .. 583.333	23 = .. 958.333
9 = .. 31.25	5 = .. 208.333	15 = .. 624.555	24 = .. 1000.000
	6 = .. 250.000		

Details of some of the alloys follow:

Standard gold.—The alloy used at present in all countries for gold coins consists of gold and copper. Many coins contain a small quantity of silver, but this is due to contamination of the copper with this metal, many copper ores containing silver, but in such small quantities that the separation of the two metals would not pay. As coins are subjected to considerable wear and abrasion during their circulation, the loss occasioned thereby is worthy of consideration, and all governments have a certain minimum weight for coins, below which they are not legal tender.

In the manufacture of jewelry, alloys of gold with copper, or with silver, or with both metals are used. The alloy with copper alone is termed "red," while if silver is used it is termed "white," and if both metals are alloyed with gold the caratation is termed "mixed." In most countries there are legally fixed standards for gold jewelry. In England 16, 18, and 22-carat gold is stamped, or, as it is termed "Hall marked"; in France 18, 20, and 22 carat; in Germany 8, 14, and 18 carat, and, also, under the term "joujou" gold, a 6-carat gold used for jewelry to be electro-gilt. Though this

is intended as a protection to the buyer, the price of the articles does not depend alone on the quantity of gold used, but to a great extent on the labor expended on its production, and, therefore, these legal regulations are, in many cases, illusive.

In table 60, the gold alloys legally fixed by the various governments are given, but it may be remarked that for certain ornamental articles distinguished by their color, some deviation, though within certain limits, is permitted:

TABLE 60.—*Fineness, composition, and color of certain alloys*

Fineness	Parts			Color
	Gold	Silver	Copper	
583	14	6	4	Yellow
583	14	3	7	Dark yellow
583	14	1	9	Very red
666	16	4.66	3.33	Yellow
666	16	1.60	6.40	Red
750	18	3.50	2.50	Yellow
750	18	2.50	3.50	Red

The ordinary Pforzheim gold-ware (joujou) has a fineness of 130 to 250; the finer quality is 563 fine; and the finest quality is 583 to 750 fine.

The elastic gold alloy (spring gold) contains 2.66 parts gold, 2.66 parts silver, and 5.33 parts copper.

Table 61 shows the proportions of various metals incorporated in the gold alloys used by jewelers:

TABLE 61.—*Gold alloys used by jewelers*

Carats	Parts			Carats	Parts		
	Copper	Silver	Gold		Copper	Silver	Gold
23	$\frac{1}{2}$	$\frac{1}{2}$	23	12	$8\frac{1}{2}$	$3\frac{1}{2}$	12
22	1	1	22	10	10	4	10
20	2	2	20	9	$10\frac{1}{2}$	$4\frac{1}{2}$	9
18	3	3	18	8	$10\frac{1}{2}$	$5\frac{1}{2}$	8
15	6	3	15	7	9	8	7
13	8	3	13				

Colored gold.—As previously remarked, the color of gold alloys varies according to the proportions of copper or silver used. Manufacturers of jewelry and other gold-ware make extensive use of the various colors of alloys, one article being frequently composed of several pieces of different colors. During recent years, the vogue of gold jewelry of varying degrees of green or white color has become extremely popular. From general observation of the public, it would appear that such colors are regarded as being natural with the gold, instead of a carefully prepared alloy. Table 62 gives the composition of the alloys most frequently used, with their specific colors:

TABLE 62.—*Composition and color of gold alloys*

Parts					Color
Gold	Silver	Copper	Steel	Cadmium	
2 to 6	1.0	.....	.....	.....	Green
75.0	16.6	.....	.....	8.4	"
74.6	11.4	9.7	.....	4.3	"
75.0	12.5	.....	.....	12.5	"
1.0	2.0	.....	.....	.....	Pale yellow
4.0	3.0	1.0	.....	.....	Dark yellow
14.7	7.0	6.0	.....	.....	"
14.7	9.0	4.0	.....	.....	"
3.0	1.0	1.0	.....	.....	Pale red
10.0	1.0	4.0	.....	.....	"
1.0	.....	1.0	.....	.....	Dark red
1.0	.....	2.0	.....	.....	"
30.0	3.0	.....	2.0	.....	Gray
4.0	.....	.....	1.0	.....	"
29.0	11.0	.....	.....	.....	"
1 to 3	.....	.....	1	.....	Blue

The alloys containing cadmium are malleable and ductile, and can be used for plating. To prepare them, the constituent parts must be carefully melted together in a covered crucible lined with coal dust. The resultant alloy is then re-melted with charcoal, or powdered rosin and borax in a graphite crucible. If, notwithstanding these precautions, a considerable portion of the cadmium volatilizes, the alloy must be again re-melted with an excess of cadmium to bring it up to the required percentage.

The following gold alloys are also used:

Pine gold	Copper	Silver	Iron	Color	Carat
75	25	.....	.....	Red	18
75	25	.....	Green	18
70	30	.....	Dead leaf	16 $\frac{1}{2}$
60	40	.....	Water green; almost white	14 $\frac{2}{3}$
75	25	Blue	18

Certain alloys of gold are also prepared by an electrolytic process, and articles showing various colors are now manufactured by this method. It is generally done by immersing the article of gold in a diluted bath of gold chloride, in which is a plate of silver connected with the positive pole of a battery; silver separates upon the gold, an alloy being formed which is used as a basis for further coloring. When the desired color has made its appearance, the plate of silver is replaced by one of colored gold, whose color corresponds to the shade the article is to have.

In many factories it is customary to color the finished gold articles—that is, to impart to them by treatment with reagents capable of dissolving copper—a color approaching that of chemically pure gold. By this operation the alloy of gold and copper is decomposed on the surface of the article, the copper being dissolved out. By allowing the surface of the article to remain in contact with the bath for some time the copper is entirely dissolved, a layer of pure gold with its characteristic color remaining behind. By allowing the bath to act for a shorter time, only a portion of the copper is dissolved, and by skillful manipulation, the various shades between red and yellow can be imparted to the articles.

Yellow-gold alloys.—The old-time jewelers used nothing but silver and copper, and for some purposes these metals are excellent to-day, especially in making a tough or spring wire, plate, etc., where strength is required, as in frames for brooches, bar-pins, knife-edge work, pin-tongs, frames for eye-glasses, etc., and also snaps for bracelets. Gold, silver,

and copper alloys should be melted, rolled down, and cut into small pieces and re-melted to ensure a thorough mixing of the metals. Four examples of yellow-gold alloys are as under:

Formulas for yellow gold

	22 carat	18 carat	14 carat	10 carat
Fine gold.....	22	18	14	10
Fine silver.....	1 $\frac{3}{4}$	4	6	8
Fine copper.....	$\frac{1}{4}$	2	4	6
Total pennyweights or parts	24	24	24	24

The 14 and 10-carat alloys make a very tough alloy, suitable as explained. Still harder or more springy alloys may be made by bringing the proportions of the silver and copper more nearly even by subtracting from the silver and adding to the copper.

Red alloys.—Three of these alloys are given below:

Formulas for red gold

	22 carat	18 carat	18 carat
Fine gold.....	22	18	18
Silver.....	.....	.....	2
Copper.....	2	6	4
Total.....	24	24	24

In red alloys below 18 carat certain prepared metals are used, these usually being mixtures of copper, zinc, manganese, etc., and come in granulated form under various names corresponding to their color, as "Guinea alloy," "red alloy," etc. There is an advantage in using these alloys, as one melt only is necessary, and for die work, press work or stamping, also in all solid or stationery work, lapped or polished goods, there is a brilliant luster and softness not obtained in the copper alloys. Two red alloys including a prepared alloy are as under:

Formulas for red gold, including a prepared alloy

	14 carat	10 carat
Fine gold.....	14	10
Silver.....	2	2
Copper.....	3	5
Guinea alloy.....	5	7
Total.....	24	24

For curb chains best results are obtained by using only gold and copper, or in any event, very little silver.

Green-gold alloys.—The following mixtures make green gold:

Formulas for green gold

	18 carat	17 carat	15 carat	14 $\frac{2}{3}$ carat	14 carat
Fine gold.....	18	17	15	15	14
Silver.....	6	7	8	8 $\frac{1}{2}$	8 $\frac{1}{2}$
Copper.....	.....	.....	1	1 $\frac{3}{4}$	1 $\frac{3}{4}$
Total.....	24	24	24	25	24

The 18-carat green gold is used in flower or leaf work. The 17-carat is also used for this kind of work, but while not as dense a green as the 18-carat, and resembling, when newly chased or matted, the dewy grass at sunrise, it does not keep its color so well. The 15, 14 $\frac{2}{3}$, and 14-carat gold are used in the regular stamped 14-carat jewelry and chains. Some manufacturers, in order to get better shades of green, use the higher carat value—that is, 15, and 14 $\frac{2}{3}$ carat alloys, and stamping the same 14-carat.

White-gold alloys.—Most manufacturers prefer to buy the white-gold in the various carat qualities from refiners who make a specialty of white gold. These refiners, however, sell a white-gold alloy from which one can make his own carat quality by using the alloy only in conjunction with fine gold, for instance:

Formulas for white gold

	18 carat	14 carat
Fine gold.....	18	14
White alloy.....	6	10
Total.....	24	24

Place the alloy at the bottom of the crucible, cover with gold, and melt with boracic acid crystals only. Pour rapidly as possible. Melt twice to get best results.

White-gold alloys are made from nickel, traces of iron, palladium, silver, and zinc. Gold, nickel, and zinc alone make a white gold, but it would not pay the average jeweler to install the necessary equipment needed to regulate temperatures at which the various metals have to be placed in the crucible. Nickel only mixes with gold at a high temperature. The heat then must be brought down to permit of the zinc being introduced, as otherwise it would volatilize. The melting points of these metals are nickel, 2705° F.; gold, 1945° F.; and zinc 787° F. Silver melts at 1761° F.

Gold solders.—Five mixtures for solders are given below:

Formulas for gold solders

	15 carat	12 carat	10 carat	8 carat	6 carat
*Fine gold.....	15	12	10	8	6
Fine silver.....	7½	9½	11	12	14
Fine copper.....	1½	2½	2¾	3¾	3½
Brass.....	.....	.....	¼	¼	½
Total.....	24	24	24	24	24

* For expediency it is best to weigh and work as above. Any quantity can be melted by multiplying or subtracting all the numbers by the same figure, so:

	15 carat	Or, multiply by 4 for a 96-pennyweight melt
Fine gold.....	15 pennyweights	60 pennyweights
Silver.....	7½ "	30 "
Copper.....	1½ "	6 "
Total.....	24 pennyweights	96 pennyweights

The 15-carat solder is used on 18-carat work, the 12 and 10-carat on 14-carat work, and the 8 and 6-carat on 10-carat work. Some manufacturers use more brass, but it is generally best to use less, otherwise it makes poor solder if used in excess, and tends to burn holes in the work. A grain or two of zinc is sometimes thrown in immediately before pouring. In making solders where brass is used, always melt the gold, silver, and copper first, and mix well; then add brass, poking it down under the charcoal, and as soon as melted, pour.

The gold used in all the tables is 24 carats and the silver fine, both as they come from the Assay Office, through the bank or refiner. The copper is the best shot metal supplied by material houses. The brass is the common high or yellow product, and generally works best in wire form about $\frac{1}{8}$ inch thick and cut in lengths not longer than $\frac{1}{2}$ inch. The melting of coins is not commended where it can be avoided, as the carat qualities vary in different countries, and besides, this is a practice not liked by governments—in fact, in England it is against the law. It is best in the long run to melt old gold scrap into a lump, and send it to a refiner in exchange for fine gold.

Alloys of gold and palladium.—By alloying 1 part of palladium with 1 part of gold a gray alloy is formed. It has the color of wrought iron, is less ductile than either of the component metals, and has a coarse-grained fracture. A hard, ductile alloy is formed with 1 part palladium and 4 parts gold, and an almost white alloy with 1 part and 6 parts, respectively. Alloys of gold, copper, silver, and palladium have a brownish-red color, and are as hard as iron. They are sometimes used for bearings of the arbors in fine watches, as they cause the minimum of friction (less than the jewels used for the same purpose), and do not rust. A typical alloy for watches consists of 18 parts gold, 13 parts copper, 11 parts silver, and 6 parts palladium. For parts of watches which require to be very hard, an alloy of 80 parts gold and 20 parts palladium is also used.

Alloy of aluminum and gold.—This alloy, also known as “Nuremberg gold,” is frequently used in the manufacture of cheap gold ware, it being well adapted for this purpose as its color exactly resembles that of pure gold, and remains unchanged in the air. The composition of most articles of Nuremberg gold is 90 parts copper, 2.5 parts gold, and 7.5 parts aluminum.

An addition of cadmium to an alloy of gold and silver imparts to it a beautiful green color. These alloys will be referred to in speaking of colored gold.

SILVER ALLOYS

As pure silver is too soft a metal to be used industrially, articles made from it are never pure, unless, as in the case of certain chemical apparatus, which may be pure because the alloys of silver would be corroded by the substances used therein. In order to impart hardness, silver is alloyed with other metals, chiefly copper. The so-called “standard” or “sterling” silver must contain at least 925 parts of pure silver in 1000 parts, otherwise it cannot be called sterling, and in many countries there are laws which establish this standard. This generally consists of 92.50% silver and 7.50% copper. In making the alloy, the copper and silver are put together into a crucible and melted in the same manner as bronze, using a cover of charcoal on the metal. The purest copper should be used, and strange as it may appear, the 7.50% of copper renders the silver so hard that it will require several annealings during rolling operations.

Silver alloys are expressed in parts per thousand, and not in percentages as is the case with the ordinary alloys of copper. The rather peculiar standard known as sterling appears to be due to the particular system of weights used, the fineness of silver coinage having been from very early times computed by divisions of the troy pound, in which system, standard silver contains 11 oz., 2 dwt. of fine silver, and 18 dwt. of copper, or other metal in the troy pound.

What are known as "assay silver bars" are rectangular ingots of silver produced by the United States Assay Office in New York City. They are usually 999 fine—that is, they will contain 1 part in one thousand of impurity, or 0.10%. The following analysis of an average bar of Government or Assay silver will show what the impurities usually consist of: Silver, 99.929%; copper, 0.056%; lead, 0.003%; gold, 0.007%; antimony, 0.002%; arsenic, 0.001%; iron, 0.001%; zinc, trace, and tellurium, 0.001%; equal to a fineness of 999.29.

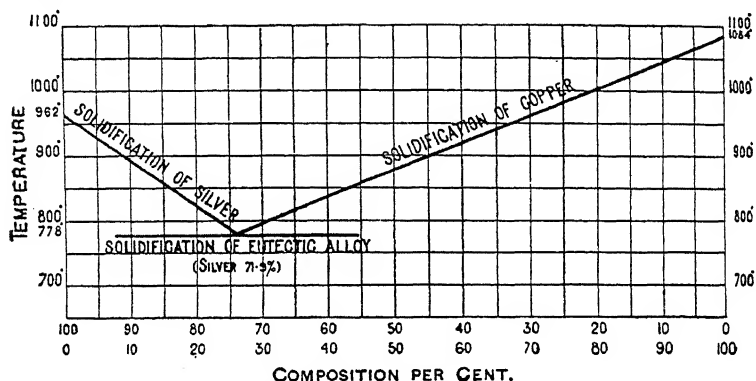


Figure 82.—Freezing curve of copper-silver alloys.

When silver is melted it takes up oxygen—about 22 times its volume—and the copper that is alloyed with it also introduces more oxygen in the shape of cuprous oxide. When the silver cools after pouring it gives up the oxygen, causing the phenomenon known as "spitting" or "sprouting." The presence of oxygen interferes with rolling and drawing operations, and to prevent these troubles the silver has to be deoxidized. The deoxidizer—cadmium—used is peculiar to silver, and in regard to its use in silver alloys we cannot explain the matter better than by quoting from an article on the use of cadmium in sterling silver by the late Erwin S. Sperry in *Brass World* of Feb., 1906:

Pure silver itself is not a difficult metal to cast if care is taken to keep it well covered with charcoal to prevent spitting. The

copper that is added to it, however, in order to make sterling silver by the simple method of melting the ingredients—silver and copper—succeed in obtaining castings which look well, but do not work under the spinning tool or in the drawing press with any degree of success. The oxide of copper which is formed during the melting is the cause of the difficulty. The more oxide copper contains the less malleable it is. The presence or absence of copper oxide in sterling silver determines whether the sheet metal will be good or bad. Much nonsense has existed in the silver industry. The melting has been the subject of all the fantastic methods which only melters can evolve. Nostrums, fluxes, and ridiculous methods of every description have been used. Some of the methods date back to the early days of metal manufacture. One of the relics of barbarism is the so-called “steel method” of melting sterling silver by putting a piece of steel on the silver while it is melting. One by one manufacturers have abandoned this method of melting until there are only a few who practice it.

In the United States Mint, coin silver (900 parts of silver and 100 parts of copper) is allowed to remain in the fire for a long period in order to refine it. To be sure the metal is kept covered with fine charcoal, but no copper alloy is benefited by such treatment. It is well that the Mint uses its own silver and does not have to draw or spin it, because if they did, it is quite certain their refining methods would cease.

Various elements have been tried for reducing the copper oxide which forms when silver is melted, such as aluminum, phosphorus, zinc, manganese, silicon, and magnesium, but the cure is usually worse than the disease, as these elements leave behind them worse things than blisters, or lack of malleability.

So far, cadmium has been found the most satisfactory addition to sterling silver. It has a strong affinity for oxygen, and so reduces the oxide to metallic copper, then it alloys with silver in all proportions; a large amount does not render the silver brittle, and it is white, and for some unexplained reason, it produces a white color in the sterling silver mixture. Even when only 5 oz. of cadmium is added to 1000 oz. of sterling silver, the color is much whiter than otherwise. Probably this is due to the reduction of the copper oxide. To use cadmium in the manufacture of sterling silver, the following mixture should be made:

	Ounces
Fine silver.....	462.50
Lake copper (Michigan).....	35.00
Cadmium.....	2.50
Total.	500.00

If the cadmium is put into the crucible with the copper and silver, it would be completely volatilized before the silver and copper

were melted, so for this reason it is left until the mixture is melted and ready for pouring.

The granulated copper should be put in the bottom of the crucible and the silver on top. Then cover with charcoal and melt, taking care that all the copper is melted. The cadmium is now added, by submerging it under the molten metal by means of a pair of tongs; if it were thrown on top of the molten mixture it would simply burn away and not enter. The mixture should then be stirred carefully and afterwards poured into the molds. Cadmium gives excellent results in sterling silver mixtures for casting in plaster molds, also in sand molds. The castings are sounder and the metal runs better. In the latter case, however, the amount of cadmium should be doubled, as it has been found that this makes for less pin-holes in the castings.

The advantages of cadmium in sterling silver are a great increase in the malleability and ductility of the alloys, and therefore, they are more easy to spin and draw. Its use has been found so satisfactory that practically every manufacturer of sterling silver in the United States is using it in the manufacture of his sterling silver sheet.

The constitution of the silver-copper alloys has been thoroughly investigated by the late Sir W. C. Roberts-Austen, also by Haycock and Neville,* and the results of their investigations are plotted in the freezing-point curve shown in figure 82. It will be noted that the metals form a simple series of alloys with a eutectic containing 71.90% of silver and 28.10% of copper, and melting at 779° C. (1434° F.) the lowest temperature of any of the series. The eutectic alloy differs from the other members of the series in that it is comparatively brittle and possesses a lower tenacity than the other silver-copper alloys. Standard silver contains more silver than the eutectic alloy, and consequently is not homogenous. The difference in composition, however, never exceeds 1 or 2 parts per 1000 when proper precautions are taken in melting and casting the alloy, such differences not being sufficient to interfere seriously with the application of the alloy in minting and for industrial purposes. But this segregation is a matter requiring careful watching, as any carelessness on

* The Properties of Standard or Sterling Silver, with Notes on its Manufacture, by Ernest A. Smith and Harold Turner, *Journal of the Institute of Metals*, vol. 22, page 152.

the part of the melter may easily result in ingots in which the variations in composition are much greater than those given.

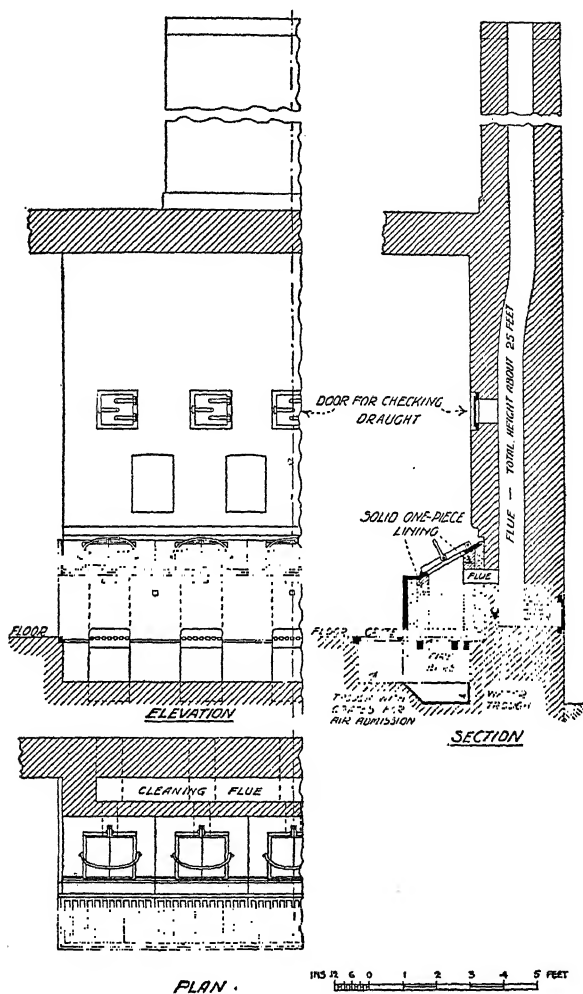


Figure 83.—Coke-fired silver-melting furnace (Smith and Turner).

Silver melting furnaces.—In figure 83 is shown a modern coke-fired pit furnace for melting silver. This is used at the works of William Turner & Co., Sheffield, England, and was

described by Ernest A. Smith and Harold Turner at a meeting of the Institute of Metals held on September 24, 1919, at the University of Sheffield (See *Journal of Institute of Metals*, vol. XXII, 1919, p. 149).

Such furnaces have been found well-suited for the work of melting silver, and have a long life. Their special features are: the solid one-piece lining, the water-trough, draft check-doors, and doors for flue cleaning. The flue sweepings carry considerable silver, and so are worth treating for its recovery. To ensure regular operation, each furnace has an independent stack 25 feet high. The consumption of coke in such furnaces is given at 25 lb. per 1000 oz. of silver melted, when foundry coke is used, but the consumption is greater with gas coke. The coke should be as free as possible from sulphur, as a standard alloy (92.5 parts silver, and 7.5 parts other metal, usually copper) has a great affinity for sulphur, which, if present in appreciable quantities, renders the metal unfit for rolling. The average amount of sulphur found in commercial sheets of standard silver is about 0.003%. The exacting demands of the present day compel refiners to reduce the impurities to the lowest possible amount.

Fine silver.—To be called "fine," the silver must not be under 998.0 pure—that is, 998 parts in 1000. A very pure grade of copper should be used in alloying. During the melting period the surface of the metal is kept covered with charcoal, which keeps in the heat and protects the metal from oxidation by the air.

Among the papers of the symposium on non-ferrous electrometallurgy at the 40th general meeting of the American Electrochemical Society in September was one entitled "Electric Silver Melting," by H. A. DeFries. This created a great deal of attention and gave rise to lengthy discussions. By this process, the high cost of graphite crucibles is eliminated, also the need for an experienced melter, which are essential to gas or oil-fired crucible practice. Distinction was made between the pouring temperatures of bar silver (1038 to 1093° C.) and of rolling mill and casting silver (1293 to

1304° C.), when casting horizontal molds. Mr. Hogaboom emphasized the importance of a high pouring temperature, which can be so readily attained in the electric furnace. Mr. Northrup of Trenton, N. J., reported that over 1,000,000 oz. of silver had been melted in his electric furnace.

Mr. DeFries also had a paper published* under the caption "Melting Fine and Sterling Silver by Electricity." Great care must be exercised in handling molten silver between a furnace and molds, as a difference of only 100° C. will produce crystallization, with attending brittleness. During melting, the silver should not be disturbed by stirring or rocking, as the protective cover formed, which protects this metal from gases, if broken, would allow the oxygen in the gases and air to be absorbed by the metal. An absolute oxygen control is possible in the electric furnace, but not in an oil-fired furnace. An almost neutral atmosphere; slightly reducing, is found most suitable, and can be easily obtained in an arc furnace. If a more reducing atmosphere is required, 1 lb. of powdered charcoal to 5000 oz. of molten silver is effective. The furnace should be air-tight, and pouring should be done through a special taphole. The travel from spout to mold should be as short as possible. Molds are best smoked and heated to 205° C. Only two types of electric furnaces can be considered, namely, the indirect-arc furnace of the stationary type, and an induction furnace, such as the Ajax-Northrup. The latter possesses greater adaptability to this particular work. Mr. DeFries used a furnace of the Rennerfelt type, of 10,000-oz. capacity. The average charge was 4000 oz., and power consumption 330 kw.-hr. per ton (30,000 oz.) of silver. The Ajax-Northrup furnace uses 320 kw.-hr. Lining for the indirect-arc furnace should be either of silica brick or firebrick, with a hearth of gannister or carborundum, which is wetted with sodium silicate, rammed well, and thoroughly sintered with the arc. Such a lining will last indefinitely. Not more than 5 oz. per 10,000 oz. melted should

* *Chem. Met. Eng.*, vol. 25, 1921, p. 507.

be lost. Electrode consumption will average 5 lb. per ton of metal. The furnace will produce 60,000 oz. in 8 hr. at a total cost of 77 cents per 1000 oz. In comparing electric and crucible silver it is found that the former has a much finer grain, is easier to roll, stamps perfectly, gives 85% better forgings, and is 100% perfect in spinning (against failure for crucible silver).

In his paper * on electric furnaces for silver, gold, and metals of low melting point, Jonas Herlenius said that the electric furnace has the following main advantages over fuel-heated furnaces: (1) A more perfect temperature control; (2) less loss by oxidation through a neutral or reducing atmosphere; and (3) higher efficiency. He then discussed six types of electric furnaces, but eliminated the direct-arc type which causes an excessive loss by volatilization. The melting point of silver is 960° C., and its boiling point 1950° C., and the pouring temperature should be about 1295 to 1305° C. Accurate temperature control is necessary. Any chilling results in brittleness. The furnace must be air-tight, should have suitable working doors, and should be of the tilting type for quick pouring. The Rennerfelt free-burning arc furnace, as used at the Philadelphia Mint, is of 1000-lb. capacity, and during one campaign re-melted 3,142,000 lb. of silver dollars into bullion. The actual melting time was 50 min. for 1000 lb., and the loss was 2 oz. per 10,000 oz. melted. The average power consumed was 177 kw.-hr. per ton of metal. At another plant a 500-lb. Rennerfelt furnace melts sterling and fine silver, at a rate of one heat an hour, consuming 250 kw.-hr. per ton, plus 80 kw.-hr. for preheating, and loses 4 oz. per heat of 5000 oz. These furnaces are generally preheated to a light yellow incandescent heat before charging silver. The carbon-resistor furnaces are not as efficient as the direct-arc types. The only high-frequency induction furnace is the Ajax-Northrup, four of which are operated at the Philadelphia Mint and one at the plant of

* *Chem. Met. Eng.*, vol. 25, 1921, p. 454.

Handy & Harmon at Bridgeport, Conn. Results have been very gratifying. The Mint furnaces are stationary, single-phase units, and four charges totaling 13,490 oz. have been melted in 7 hr., consuming 156.5 kw.-hr. The H. & H. furnace, of 600 lb. capacity, reduced 36,558 oz. in 8¼ hr., using 317 kw.-hr., including preheating. The Ajax-Northrup type shows high efficiency, and will be found best for melting silver on a medium scale. This furnace is also well suited for gold, which should be melted in crucibles on account of its high value.

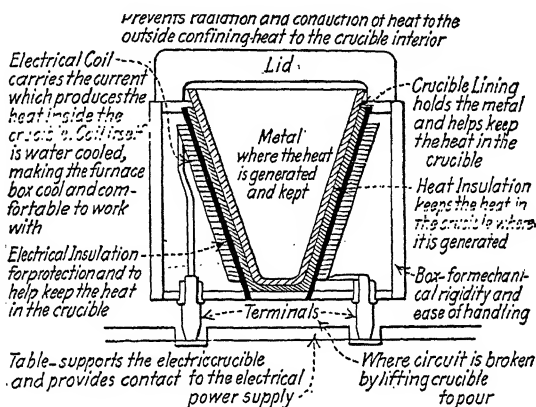


Figure 84.—Cross-section of 10-in. electric crucible.

The Ajax-Northrup furnace mentioned above was described* by E. F. Northrup, who considers that it is virtually an electric crucible. The furnace is a practical combination of crucible-melting flexibility with the advanced practice of electric melting. Later,† the same writer gave a résumé of recent progress in high-frequency inductive heating, with special reference to electric furnaces for melting precious metals, including those at the Philadelphia Mint and at Handy & Harmon's refinery. There is no doubt as to their success. Figure 84 is a cross-section of a 10-in. electric crucible, which will hold 25 lb. of steel. It is poured by being lifted out by

* *Chem. Met. Eng.*, vol. 24, 1921, p. 309.

† *Chem. Met. Eng.*, vol. 24, 1921, p. 1097.

two persons. Figure 85 is a cross-section of a small Mint furnace, which has also given good service.

Tiers-argent (one-third silver).—This alloy is chiefly prepared in Parisian factories, and as indicated by its name, consists of 33.33 parts silver and 66.66 parts aluminum. The advantages of this alloy over silver lies in its lower price, greater hardness, and the fact it can be stamped and engraved more easily than the alloys of silver and copper.

Alloys of silver and zinc.—Alloys consisting of 1 part silver and 2 parts zinc have nearly the color of pure silver,

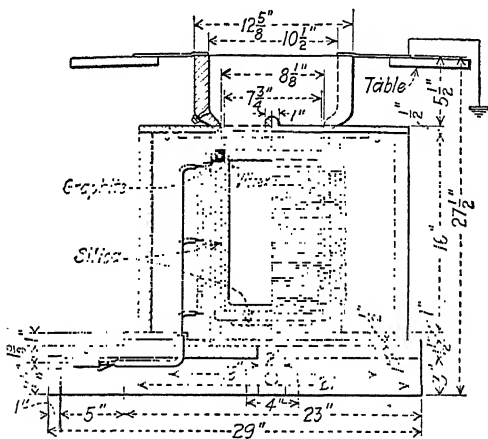


Figure 85.—Cross-section of small mint furnace.

and are ductile; but with a larger proportion of zinc the alloys become brittle.

Alloys of silver, copper, and nickel.—Nickel alone makes silver very hard and brittle, such alloys being difficult to work into utensils; but by adding some copper the alloys can be cast, rolled, and fused, and the articles manufactured from them are harder than those from silver and copper alloys. Alloys of silver, nickel and copper are much used by French manufacturers for articles formerly prepared from standard silver. These compositions may be considered as an argentan whose properties have been improved by adding silver.

Argent-Ruolz.—The articles manufactured by Ruolz, of Paris, from the so-called Ruolz silver, or *argent français*, have the appearance of pure silver, but are much cheaper and harder. According to the quality of the articles, different alloys are used, a few such compositions being given as follows, in parts:

Silver.....	33	40	20
Copper.....	37 to 42	30 to 40	45 to 55
Nickel.....	25 to 30	20 to 30	25 to 35

The argent-Ruolz sometimes contains zinc, and the following alloys may be rolled into sheet or drawn out into wire:

Silver.....	33.3	34	40
Copper.....	41.8	42	44.6
Nickel.....	8.6	8	4.6
Zinc.....	16.3	18	10.8

Alloys of silver, copper, nickel, and zinc.—These alloys have been used for the preparation of small coins, especially in Switzerland. While wearing well, the coins soon lose their original beautiful white color and acquire a disagreeable yellowish shade resembling the color of poor brass. For coinage, these alloys have the further disadvantage of the silver contained in them being recovered by a very tedious process. These coins were first used in 1850, but they were discarded in favor of pure nickel in 1881.

Moussett's silver alloy.—This consists of copper, 59.06 parts; silver, 27.56 parts; zinc, 9.57 parts, and nickel, 3.42 parts. The color is yellowish with a reddish tinge, but white upon the fractured surface.

Alloys of silver and arsenic.—These alloys may be formed by direct fusion, and the silver will retain a certain proportion of arsenic even when the temperature is very high. The compound made of 86 parts of silver to 14 parts of arsenic is of a dead grayish-white color, brittle, and acquires a metallic luster by friction. It is very fusible. An alloy composed of 49 parts silver, 49 parts copper, and 2 parts arsenic is very ductile, and has a beautiful white color. It

was formerly used for the manufacture of tableware, for which it is, however, not suitable on account of the poisonous properties of the arsenic.

Alloys of silver, copper, and cadmium.—Cadmium imparts great flexibility and ductility to silver alloys, without impairing their white color. Some of the more important alloys of this group are composed of the following, in parts:

Composition of silver-copper-cadmium alloys

Silver.....	980	950	900	860	666	667	500
Copper....	15	15	18	20	25	50	50
Cadmium.	5	35	82	180	309	283	450

In preparing these alloys, the great volatility of cadmium must be taken into consideration. The silver and copper are, as a rule, first alloyed; the cadmium is then brought into the fused mass, the whole quickly stirred and at once poured into molds. By this procedure, volatilization of the cadmium is best prevented.

Silver is also used in the preparation of other alloys, particularly in connection with platinum, which will be referred to later on. No true alloys of silver and iron have been made, only more or less intimate mixtures, in which silver appears in the shape of drops or filaments. The alloys of silver with cobalt and chromium are generally very hard and brittle, and thus far have found no application in the industries.

Alloys of silver and copper.—These alloys are more used than any other compounds of silver, and in most countries form the legal composition of coins and silverware. Silver and copper are easily alloyed in all proportions, the combination taking place with expansion, and its specific gravity is less than that calculated from the proportions of the component metals. The copper imparts to silver greater hardness, strength, and toughness, the alloys acquiring the property of giving out a melodious sound. The presence of copper does not modify the color of silver so long as the proportion of the former does not exceed 40 to 50%; a

greater proportion imparts to the alloy a yellowish tint similar to that of brass, and if the compound contains from 65 to 70% of copper the color is reddish, approaching that of pure copper.

The alloys of copper and silver, though easily prepared by the ordinary process of fusion, are, nevertheless, subject to the defect of separation, or liquation, which necessitates certain precautions when running the metal into molds. When such an alloy is run into a cold ingot mold, the center of the ingot shows a lower degree of fineness than the portion nearer the sides of the mold; and even in the monetary alloys all the portions are not of the same degree of fineness.

Formerly the silver used for coinage frequently contained small quantities of gold and for this reason nearly all the older coins are treated in the mints by the wet method to recover the gold.

At the present time the fineness of all coins is determined by thousandths, the standard varying according to the size of the coins, and the laws of the different countries, from $\frac{900}{1000}$ to $\frac{750}{1000}$. A table setting forth the fineness of subsidiary coins of various nations was given in the previous edition of this book, but since the war many have been changed; for instance, Great Britain, and Canada reduced their silver coins from 916 to 500 fine. The United States coins remain as before, namely, 900 fine.

The various silver-copper alloys employed in England for manufacturing purposes are given by Gee* as follows:

Silver-copper alloys for manufacturing

No.	Silver,			Copper		
	oz.	dwt.	gr.	oz.	dwt.	gr.
1	..	18	..	..	2	..
2	..	16	..	..	4	..
3	..	15	..	..	5	..
4	..	14	..	..	6	..
5	..	13	12	..	6	12
6	..	13	..	..	7	..
7	..	12	12	..	7	12
8	..	12	..	..	8	..

* Silversmith's Handbook.

No. 8 alloy is about the commonest alloy to make without the color showing a perceptible yellow cast. The fineness of silver used in the manufacture of silverware in different countries varies from 750 to 950.

Silver alloyed with copper in the proportions given above has, in form of wire or sheet, a hardness equal to that of cold-forged copper, but by continued mechanical manipulation the hardness increases, and may be made equal to that of wrought iron. Silver is also used for casting small articles of art, but it is difficult to obtain castings entirely free from blow-holes; this evil can be readily prevented by adding to the alloy a small quantity of zinc, about 1%. The resulting castings will be homogeneous and free from blow-holes, while the ductility of the alloy is not in the least impaired by such a small percentage of zinc.

As a result of the frequent annealing required in working articles of silver they gradually acquire a steel-gray color, which is due to the oxidation of copper. Hence the finished articles must be subject to a special manipulation called "blanching." This is effected by boiling the articles in a fluid consisting of 40 parts of water and 1 part of sulphuric acid. The copper oxide readily dissolves in the mixture, leaving the surface of the article coated with a layer of chemically pure silver.

The Japanese have a remarkable series of alloys in which the precious metals replace the tin and zinc of ordinary bronze; but really their principal alloys, with the exception of bronze, are comprised in the following example given by Roberts-Austen in a paper read before the Society of Arts, on June 13, 1890. The first is called *shaku-do*, analyses of which are given on the following page.

As will be seen from the analyses, the alloy contains in addition to about 95% of copper as much as 4% of gold. It has been used for very large works; colossal statues are made of it, one cast at Nara in the 7th century being especially remarkable. The quantity of gold is, however, very variable, and certain specimens contain only 1.5% of the precious metal.

Composition of Japanese shaku-do

	A	B
Copper.....	94.50	95.77
Silver.....	1.55	0.08
Gold.....	3.73	4.16
Lead.....	0.11	
Iron and arsenic.....	Traces	
	99.89	100.01

The next important alloy used by the Japanese is called *shibu-ichi*, the following being typical analyses:

Composition of Japanese shibu-ichi

	A	B
Copper.....	67.31	51.10
Silver.....	32.07	48.93
Gold.....	Traces	0.12
Iron.....	0.52	
	99.90	100.25

There are many varieties of it, but in both of these alloys—*shaku-do* and *shibu-ichi*—the point of interest is that the precious metals are, as it were, sacrificed in order to produce definite results; gold and silver, when used pure, being employed very sparingly to heighten the general effect. In the case of *shaku-do*, it will be seen presently that the gold appears to enable the metal to receive a beautiful rich purple coat or patina when treated with certain pickling solutions; while *shibu-ichi* possesses a peculiar silver-gray tint of its own, which, under ordinary atmospheric influences, becomes very beautiful, and to which the Japanese artists are very partial. These are the principal alloys, but there are several varieties of them as well as combinations of *shaku-do* and *shibu-ichi* in various proportions, as, for instance, in the case of *kin-shibu-ichi*, the composition of which would correspond to 1 part of *shaku-do* rich in gold, and 2 parts of *shibu-ichi*, rich in silver.

Regarding the use of pickling solutions, they are made up in the following proportions and are used boiling:

Formula for pickling liquors

	Grains	Grains	Grains
Verdigris.....	438	87	220
Copper sulphate.....	292	427	540
Niter.....	.....	87	
Common salt.....	.....	146	
Sulphur.....	.....	233	
Water.....	1 gallon	.....	1 gallon
Vinegar.....	.....	1 gallon	5 drachms

The most widely employed is No. 1. When boiled in No. 3 solution, pure copper will turn a brownish-red, and shakudo, which contains a little gold, becomes purple. The effect of small quantities of metallic impurity as affecting the color resulting from the action of the pickle will be appreciated from the following remarks: Copper containing a small quantity of antimony gives a shade very different from that resulting from the pickling of pure copper; but the copper produced in Japan is often the result of smelting complex ores. The result is that the so-called "antimony" of the Japanese art metal-workers, which is present in the variety of copper called kuro-mi, is really a complex mixture containing tin, cobalt, and many other metals, so that a metal-worker has an infinite series of materials at command with which to secure any particular shade. These are used with much judgment, although the scientific reason for the adoption of any particular sample may be hidden from him. It is strictly accurate to say that each particular shade of color is the result of minute quantities of metallic impurity.

The action of the above-mentioned solutions is remarkable. Take copper, to which a small amount of silver and a small amount of gold are added: The amount of gold may be variable, and artificers often take credit for putting in much more than analysis proves to be present, but a small amount of gold—it may be only 1%—is sufficient to change entirely the character of copper, and when it is treated by

pickling solutions the result is entirely different from that if copper alone is employed. The Japanese also take copper and dilute it, sometimes half copper and half silver, sometimes only about one-third silver and the remainder copper, and that gives the beautiful series of gray alloys, which, either by exposure to atmospheric influences, by handling, or by treatment with suitable pickles, gives the beautiful series of light and dark grays of which the Japanese are so particularly fond, and to grays to which the name shibu-ichi is given. Then again, they have copper in which small amounts of impurities may be present, and the nature of such impurity and the amount, which seldom exceeds 0.2%, is sufficient to change the character of the copper.

ALLOYS RESEMBLING SILVER

There is a large number of silver-like alloys containing various metals, which are used for many purposes as substitutes for silver alloys. A few of them, together with their properties, are here given:

Warne's metal.—Tin, 10 parts; nickel, 7 parts; bismuth, 7 parts; and cobalt, 3 parts. It is white, fine grained, and difficult to fuse.

Minargent.—This alloy, which has a beautiful white color, is composed of 1000 parts copper, 700 parts nickel, 50 parts tungsten, and 10 parts aluminum.

A beautiful white alloy closely resembling silver, manufactured in Paris, is composed of 69.8% copper, 19.8% nickel, 5.5% zinc, and 4.7% cadmium.

Delalot's alloy.—This white, silver-like alloy is claimed to possess properties adapting it as a substitute for several alloys now in use. It consists of 80 parts of pure copper, 2 parts of manganese, 18 parts of zinc, and 1 part of phosphate of lime. First melt the copper, then add gradually the manganese, and when this is thoroughly dissolved, add the phosphate. Remove the scoria, and about 10 minutes before casting add the zinc. To promote the fusion of the man-

ganese $\frac{1}{2}$ part of calcium fluoride, $\frac{1}{2}$ part of borax, and 1 part of charcoal may be added.

Tournu-Leonard's alloy.—This alloy, which closely resembles silver, is prepared in the following manner: 200 parts of fine tin is introduced into a crucible heated to a red heat. When the metal is melted, add 64 parts of bell-metal, previously comminuted to about 8-mesh. Add only small portions at one time, and stir the mixture with an iron rod to effect the solution as quickly as possible. Finally add 300 parts more of tin, stir thoroughly, and pour the alloy into molds of copper or sand. By means of the copper in the bell-metal the tin is sufficiently hardened to allow of the alloy being worked into tableware, plates for printing music, and even into jewelry.

Clark's patent alloy consists of shot-copper, 1 ounce; nickel, 3 pennyweights 18 grains; spelter, 1 pennyweight 22 grains; tin, 12 grains, and cobalt, 12 grains.

Pirsch-Baudoin's alloy.—This alloy, resembling silver, is composed of 71 parts copper, 16.5 parts nickel, 1.75 parts cobalt (in the form of oxide), 2.5 parts tin, and 7 parts zinc. Some aluminum (about $\frac{1}{2}\%$) may also be added. First prepare an alloy of all the nickel, an equal quantity of the copper and the zinc; then melt this alloy together with the iron, the remainder of the copper, the cobalt, and some charcoal powder under a surface covering of charcoal powder in a graphite crucible at a strong heat. Allow the molten mass to cool, and then add the zinc, previously alloyed with copper, at a temperature just sufficient for its fusion. Take the crucible from the fire, stir the contents with a wooden stick, add the tin previously wrapped in paper, stir once more, and pour out into molds. But a small quantity of zinc remains in the alloy, the greater portion of it volatilizing during fusion.

Silver solders.—The following are two types of silver solders: (1) fine silver, 20 pennyweights; fine copper, 8; and fine brass, 2; and (2) fine silver, 20 pennyweights; and fine brass, 10. The latter is an easy running solder.

PLATINUM ALLOYS *

Platinum has many properties besides its scarcity and price to make it desirable. Its unequaled resistance to heat and nearly all corrosive agents, its low coefficient of expansion, its ductility when pure, its hardness and stiffness when properly alloyed, as well as its pleasing neutral color, are the more conspicuous qualities which have increased its usefulness.

Like gold, which platinum resembles in many ways, it is soft and ductile when pure, and for many purposes must be hardened. Unfortunately, there are few suitable metals for hardening platinum, and those that can cheapen it are still fewer.

The principal physical properties of platinum may be expressed as follows: †

Physical properties of platinum

Atomic weight.....	195.2
Specific gravity.....	21.4
Melting point, °C. and °F.....	1755 and 3191
Hardness:	
Brinell, hard worked.....	90
Brinell, annealed.....	35
Scleroscope, hard worked.....	14
Scleroscope, annealed.....	8
Expansion, temperature coefficient of linear, at 0° to 100° C.	0.00000884
Conductivity, thermal:	
At 18° C.....	0.1664
At 100° C.....	0.1733
Tensile strength of 1 mm. wire:	
Hard drawn, kg.....	31
Annealed, kg. (with elongation at rupture up to 60%).....	24
Resistance:	
Annealed c. p. metal, ohms, per mil ft.....	60
Annealed commercial metal, ohms, per mil ft.....	90
Temperature coefficient of resistance:	
Hard drawn, per ° C.....	0.003917
Annealed, per ° C.....	0.003923

Current required to fuse platinum wire, according to Preece's formula:

$$D = \left(\frac{C}{A} \right)^{\frac{2}{3}}$$

D = diameter of wire in inches; C = current in amperes required to fuse the wire; A is a constant 5172.

* This section was written by Miss C. M. Hoke, B. S., A. M., of Jewelers' Technical Advice Co., New York City.

† From Data Concerning Platinum, 1921, by Baker & Co., Inc., Newark, New Jersey.

Associated with platinum in nature are the five other metals of the platinum group—namely, iridium, palladium, osmium, rhodium, and ruthenium—and no discussion of platinum can be made without frequent reference to them.

Commercially pure platinum, called "soft platinum," generally contains about 1% of iridium, probably with traces of the other metals, which were present in the ore and not removed by refining. "Hard platinum" should contain from about 5 to 30% of iridium; the more iridium the harder, stiffer, and more acid-resisting the alloy, also the higher the melting point. As before, traces of the other metals of the platinum group are likely to be present, and also traces of calcium and iron. Owing to the high price and great scarcity of iridium (more costly than platinum, and only a few thousand ounces produced annually throughout the world), other hardening agents are being used, but none of these is as satisfactory as iridium. By a strange inversion of terms among jewelers, the 95-5 platinum-iridium alloy is called "5% platinum"; if the iridium content is 10% it is called "10% platinum," but it is better to speak of 5% iridio-platinum, and so forth, letting the numeral refer to the iridium content.

Of the 4,000,000 troy oz. of platinum that have so far been produced in the world, plus the 400,000 oz. of allied metals, it is estimated that about 1,000,000 oz. are in dental use, 1,400,000 oz. in one or another kind of chemical apparatus, and 500,000 oz. each in electrical instruments and jewelry. The alloys utilized in each industry will be considered separately, as follows:

Chemistry and electricity.—For crucibles, dishes, and the like, commercially pure or "soft" platinum is generally used. The presence of iridium makes the metal more resistant to acids, alkalis, etc., and when the article is to be exposed primarily to these agents, iridio-platinum is indicated. But if the article must maintain a standard weight under prolonged heating, the purest and softest platinum is advised, as iridio-platinum loses weight sensibly on long ignition. Platinum crucibles, electrodes, triangles, spatulas, wire, etc., are

of the greatest importance in every branch of chemistry and chemical industry. About 400,000 oz. are used as catalyzing material in various processes, notably in the manufacture of sulphuric acid and the fixation of atmospheric nitrogen—both being processes of the greatest basic importance. (A catalyst is a substance whose mere presence promotes a chemical action, without itself being consumed or changed in any way. For this purpose platinum is generally used pure, as gauze or in the finely-divided form known as “platinum black.”) So valuable is platinum in all chemical fields that an embargo was declared upon it during the World War. This was primarily for the protection of the great sulphuric-acid industry, which is the basis of all munitions (as well as most other industries). Fine platinum wire is also consumed in detonating caps in various forms of explosives.

The Le Chatelier thermocouple for measuring high temperatures, uses one wire of the purest platinum, combined with another of a carefully made alloy of 90% of platinum with 10% of rhodium.

Platinum is also used in X-ray tubes, vacuum tubes used in wireless telegraphy and telephony, for cauteries, for the tips of lightning rods, etc.; while iridio-platinum is used in hypodermic needles.

On account of its low coefficient of expansion—almost the same as that of glass—soft platinum has been largely used as the leading-in wire in electric-light bulbs and vacuum tubes. Some excellent substitutes of base metals are also used.

Pure platinum, as well as carefully prepared alloys with other metals of its group, is used for making standard weights and measures.

The unequaled resistance of platinum to oxidation, even at high temperatures, makes it peculiarly valuable for contact points in many kinds of electrical instruments. Iridio-platinum carrying as high as 30% of iridium (generally less) is the best material for this purpose. Its high cost has brought about the use of many substitutes, some involving rare metals.

Dental alloys.—Platinum is useful in dentistry owing to

its resistance to the acids of the mouth, also on account of certain physical properties. When an elastic, springy alloy is needed, such as for the cast clasps used in modern prosthetic dentistry, a gold alloy containing platinum is indicated. The melting point must be high, as other parts must be soldered to it without injuring its elasticity. The exact color is not a matter of great moment. Following are two formulas for dental work:

*Formulas of typical dental clasp metals**

Metals	Per cent	Per cent	Parts
Fine gold.....	64.0	65.0	20
Silver.....	1.5	6.0	1
Copper.....	7.0	7.0	2
Platinum.....	11.0	18.0	1
Palladium.....	16.5	4.0	
Total.....	100.0	100.0	24
Melting point, ° F.	2100	1960	

The palladium in these alloys has the function of making the mixture of smooth and workable texture; without it the product would be brittle.

Iridium is not desirable in this type of alloy, and for high quality work it must be carefully excluded. However, for dental pins, where stiffness and rigidity are required, combined with a high-melting point, 10% iridio-platinum is recommended. The high cost of this alloy has resulted in many substitutes, such as nickel pins coated with a thin shell of platinum; or pins in which iridium has been replaced by more or less palladium and gold. Some alloys of tungsten and molybdenum have also been employed.

Jewelry.—The ideal metal for jewelry is iridio-platinum. Its permanent value is only one factor. Foremost of its qualities is its great mechanical strength, which permits the jeweler to construct designs of gossamer daintiness without sacrifice of security. Valuable gems are held firmly, though

* For a full discussion of dental alloys, see Weinstein's chapter in Peeso's "Crown and Bridgework;" also in *Dental Digest*, May-Dec., 1918.

so little metal is required that only a small part of the stone's surface is hidden. It takes a high polish, and never tarnishes. Its faintly bluish color greatly enhances the beauty of most stones, especially diamonds. Delicate chains and mesh are of surprising strength; they may contain as much as 25% of iridium in high-grade articles. In parts of the design that require less strength, 5% iridio-platinum is used; 10% is the average.

The high price and increasing scarcity of iridium has resulted in the use of other hardeners, to replace it either wholly or in part; but none is really satisfactory. Perhaps the best substitute for iridium is a combination of palladium and gold. Gold alone will harden platinum, but makes it brittle; palladium alone gives a soft alloy. The two together give an alloy resembling iridio-platinum in appearance and working quality, but of lower melting point and resistance to acids. Typical alloys of this class are as under:

Metal	Per cent	Per cent	Metal	Per cent
Platinum.....	81	95.3	Platinum.....	70
Palladium.....	14	0.2	Palladium.....	25
Fine gold.....	5	4.5	Iridium.....	5
Total.....	100	100.0	Total.....	100

Less satisfactory hardeners are nickel or iron, of which usually only small amounts can be used—5% or less—and the alloy is stiff and hard, of good color, but difficult to work. The main objection to an alloy of this type appears when the scrap metal must be re-melted. (In making platinum jewelry, considerable scrap is produced, sometimes surprisingly much, which must be re-melted and used, and the process repeated several times.) When base metals have been employed as hardeners, re-melting is difficult, because at the very high temperature required the base metals oxidize readily. When gold and palladium are used as hardeners, the re-melting is generally successful, perhaps with some slight loss. If properly done, the re-melting of iridio-platinum need cause only negligible losses.

Stamping Law.—Federal laws regulating the stamping of gold and silver have been in force for a number of years, and the need for a similar law for platinum is obvious. The State of New York has a law which requires that if an article be stamped, or even described as platinum in label or invoice, all parts that appear to be platinum must assay at least 925/1000 platinum group metals. As long as palladium is the cheaper (as well as much the lighter) metal, it is plain that this law is too indefinite. Efforts were being made in December, 1922, to frame a Federal law to regulate the use of these metals more sharply.

MELTING PLATINUM AND ITS ALLOYS

Platinum.—As late as 1910 the melting of platinum was an uncommon process, only a few large refiners being able to

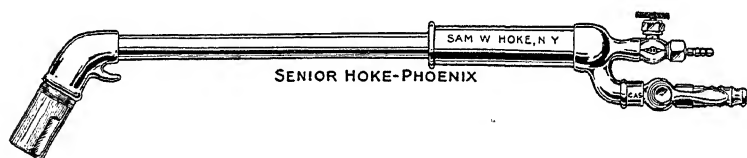


Figure 85a.—The Hoke-Phoenix torch for melting platinum or alloys thereof.

do it. Now, however, with the introduction of a proper torch and cheap commercial oxygen, hundreds of jewelers, small refiners, and others, are melting platinum every day. This applies to virgin platinum, refined metal, and re-melted platinum scrap. The large majority of platinum melts are made in the following manner:

The Hoke-Phoenix torch, shown on figure 85a, is the standard torch for this purpose. It is of rather simple construction, and burns ordinary city gas in connection with oxygen from a cylinder, giving a temperature of about 4000° F. Natural or artificial gas can be used, or if these are not available, hydrogen or even acetylene may be substituted. The oxy-acetylene flame is much hotter than needed, and is not so easily managed. The metal is placed, without

flux, in a shallow sand crucible with one high side. An old-fashioned Hessian crucible can be used by breaking one side down almost level with the bottom. The method is extremely simple; a naked flame is turned directly upon the naked metal, and in a few minutes the metal is in a button.

A slightly oxidizing flame is used, and if traces of base-metal impurities are present, they are burned out. Gold, if present in small amounts, will boil away, leaving a bronze or purple stain on the upper part of the crucible. Gases are not absorbed to any noticeable extent. The button is removed from the crucible as soon as it freezes, and while white hot, it is hammered to a bar or block of the desired shape for drawing or rolling. Graphite crucibles can be used, but are more expensive and not so well liked. Melts as large as 118 oz. have been made in 11 minutes by this method.

Larger melts—as much as 150 oz.—are handled in a slightly different manner, though the same torch is used. In exceptional cases two torches can be used at once. When platinum was first melted and worked, a lime crucible was used, and in some cases lime is still used for large melts. A block of freshly calcined quicklime is bound in iron, and a saucer-shaped pit is hollowed out. A lid is provided, also of lime, with two holes set at an angle; the torch enters through one hole, and the products of combustion go out the other, suggesting a reverberatory furnace. Sometimes a spout is cut, and the block is arranged to tilt and pour the molten metal. Sometimes the pit that holds the metal is cut in a rectangular shape. As the metal cools and freezes quickly, small melts are not easily poured. Molds of graphite are used, or preferably steel molds lined with sheets of platinum, which become one with the new ingot.

An improvement on the old lime crucible is the zirconia crucible. It is shaped somewhat the same—with a spout and a lid—and is pivoted for pouring. It does not break up on heating like lime, and can be used dozens of times. Moreover, it has less tendency to contaminate the metal than lime. Only its high cost stands in the way of greater use.

Sometimes, on account of local conditions or the need for special purity, pure hydrogen is used instead of city gas; but if extraordinary purity is desired, as in the case of special scientific investigations, and freedom even from included or occluded gases is required, an electric vacuum furnace may be used. This is expensive and slow, and only small quantities can be handled.

Platinum alloys.—Iridio-platinum is prepared in the same manner as platinum is melted; the two metals, in the form of scrap, sponge, or black, are mixed well and then simply melted together. Sometimes the crucible is rocked from side to side to assist mixing; or the button is rolled out and re-melted to the same end. These alloys melt at a higher temperature than soft platinum, 25% iridio-platinum being noticeably slower to fuse.

Platinum-palladium-gold alloys are melted in the same way, except that a lower temperature will serve. Palladium has the curious ability of absorbing large quantities of gas (especially hydrogen) when hot, and sometimes the metal swells and spits. This can be avoided by letting the melt cool slowly, heating again if swelling appears. No flux is needed.

The dental alloys which contain copper and silver, as well as the more precious metals, are melted as follows: First melt the platinum, palladium, and gold together, into several small buttons—as just described. Then place these buttons in an ordinary sand crucible, add the silver and copper, and melt as one would melt gold, using a flux of argol (potassium bitartrate). Heat in a gold-melting furnace, or use the Hoke-Phoenix torch, allowing it to play upon the outside of the crucible, and using a slightly smoky flame.

Alloys of platinum with small amounts of base metals—such as the platinum-nickel and platinum-iron alloys described above—are made in the same manner as iridio-platinum, save that efforts must be made to prevent oxidation. One way is to wrap the base metal tightly in platinum foil, and then plunge this into the molten platinum. Another is to mix the finely-

divided base metal with finely-divided platinum sponge, and melt the whole as quickly as possible, using a gentle flame.

If only a small amount of platinum is to be introduced into a large quantity of base metal, the temperature of a gas-air furnace is high enough. For while platinum has a high melting point (1755° C. or 3191° F.), if surrounded by molten copper or silver, for example, it will dissolve in it, after the manner of gold in mercury. But such melts are rarely made.

OTHER METALS OF THE PLATINUM GROUP

Iridium itself is hard, brittle, refractory, and extremely insoluble in any acid or combination of acids. Besides being used as an alloy with platinum, it is employed in conjunction with osmium. Naturally-occurring grains of osmiridium are much used for tipping gold pen points; their great hardness and resistance to inks making them desirable for this purpose.

Osmium is unusual in forming a volatile oxide. When heated strongly, whether alone or in conjunction with other metals, poisonous fumes are evolved, and may result in blindness to the worker. Osmium has been used as a hardener in place of iridium, but the danger attached to re-melting that alloy is enough to discourage its employment.

Palladium is rarely used as a pure metal, except as a catalyzer. It differs from the others in being soluble in nitric acid. Its great usefulness is as an alloying material, particularly in conjunction with the other precious metals. The palladium-platinum-gold alloys have already been mentioned. Palladium-gold alloys are also important; the two metals alloy well in all proportions, giving white, easily worked alloys, whose characteristics are such as to make them valuable as platinum substitutes. A 10-90 palladium-gold alloy is almost white. The 20-80 palladium-gold alloy, called "Palau," makes an excellent substitute for platinum for many purposes. Palau crucibles and chemical ware, while they do not serve all the uses of platinum, are of great value as plati-

num sparers. Palladium-gold alloys, with or without other ingredients, are the bases of the higher quality white-gold alloys used in jewelry as substitutes for platinum. They are non-tarnishing, of good color, but have not the fine rigidity and strength of iridio-platinum, and do not retain their polish so well. Palladium-silver alloys, and palladium-gold-silver alloys have been suggested for dentistry, many formulas being possible. In all of these alloys the palladium has the rôle of the whitener and the softener. The 18-carat palladium-gold alloy (palladium 75%, gold 25%) is as white as platinum, and almost as soft.

Rhodium is little used, except in the thermocouple mentioned.

Ruthenium also is little used, but may find service as a hardener in place of iridium. It also forms a poisonous volatile oxide.

OTHER PLATINUM ALLOYS

Platinum-gold alloys.—If small amounts of gold are introduced into platinum, the color of the latter is at once darkened, and the product is brittle and hard. If, on the other hand, small amounts of platinum are melted with much gold, a workable alloy of golden or brass color appears. In the old days, platinum was largely used to adulterate gold. Thus, a 14-carat gold containing platinum will have the same density and resistance to acid as ordinary 18-carat gold.

Platinum-silver alloys.—If a little silver is added to much platinum, the result is dark and brittle. If a little platinum is added to much silver, the result is a series of workable alloys, though of not enough value to justify their expense. A 33-66 platinum-silver alloy has been used successfully in jewelry.

Platinum-copper alloys.—A little copper present as an impurity in platinum makes it dark and brittle. "Cooper's gold" contains 3 parts of platinum to 12 parts of copper, and looks like gold. It was once used as an imitation, but at present prices it has no function.

Platinum with non-metals, such as sulphur or phosphorus, gives brittle compounds or mixtures.

Platinum with other base metals, such as aluminum, arsenic, bismuth, manganese, magnesium, etc., yields only brittle alloys.

The following table gives some of the properties of the metals of the platinum group:

TABLE 63.—*Properties of the platinum group metals*

Metal	Specific gravity	Melting point		Atomic weight	Symbol
		° C.	° F.		
Platinum.....	21.37	1755	3191	195.2	Pt
Iridium.....	22.42	2350	4262	193.1	Ir
Osmium.....	22.48	2700	4892	190.9	Os
Palladium.....	12.16	1549	2820	106.7	Pd
Rhodium.....	12.44	1950	3542	102.9	Rh
Ruthenium.....	12.06	2450	4442	101.7	Ru

CHAPTER XXII

FUSIBLE ALLOYS: CADMIUM AND BISMUTH

CADMIUM

CADMIUM shares with bismuth the property of considerably lowering the melting points of alloys, but while the bismuth alloys are nearly all brittle, many alloys of cadmium possess considerable ductility, and can be worked under the hammer as well as between rolls. They act, however, very differently in this respect, there being alloys that are very ductile, and others again, though containing in addition to cadmium the same metals only in different proportions, which are very brittle.

An alloy consisting of, say, cadmium and silver, shows this phenomenon in the most remarkable manner. By melting together one part of cadmium and one to two parts of silver a very ductile alloy is obtained, which can be rolled out to a very thin sheet; but an alloy of two parts of cadmium and one of silver is so brittle as to break into pieces under the hammer.

As cadmium imparts to the alloys a very low melting point, it is frequently used in the preparation of very fusible solders, for casting articles not to be exposed to a high temperature, and in dental compounds for filling teeth.

Alloys of cadmium generally contain tin, lead, bismuth, and sometimes mercury, the last mentioned being added chiefly to lower the melting point still more. Alloys of cadmium and mercury alone (cadmium amalgams) are solid and malleable, hence the addition of mercury does not impair their solidity.

Lipowitz alloy.—This alloy is composed of 3 parts of cadmium, 4 parts of tin, 15 parts of bismuth, and 8 part of lead. It is best prepared by heating the comminuted metals in a crucible, and stirring, as soon as fusion begins, with a stick of hard wood. This stirring is of importance in order to

prevent the metals—whose specific gravity varies considerably—from depositing themselves in layers. This alloy softens at 140° F., and melts completely at 158° F.

Lipowitz metal has a silvery-white color, a luster like polished silver, and can be bent short, hammered, and worked in the lathe. It, therefore, possesses properties adapting it for many purposes where a beautiful appearance is of special importance; but on account of the considerable cadmium and bismuth content, the alloy is rather expensive and finds but limited application. Castings of small animals, insects, and reptiles have been prepared with it, which in regard to sharpness were equal to the best galvano-plastic products. Plaster of Paris is poured over the animal to be cast, and after sharply drying, the whole animal is withdrawn from the mold and the latter filled up with Lipowitz metal. The mold is then placed in a vessel containing water, and by heating the latter to boiling point, the metal is melted and deposits itself in the finest impressions of the mold.

The alloy is very suitable for soldering tin, lead, etc., and on account of its silver-white color is especially adapted for soldering Britannia metal and nickel; but its cost prevents its general use for this purpose, and cheaper alloys having nearly the same properties as Lipowitz metal have been prepared.

The following table gives details of other alloys of cadmium:

TABLE 64.—*Sundry cadmium alloys*

Name	Use	Melting point, ° F.	Cad- mium	Tin	Lead	Bis- muth	Remarks
....	....	170	2	3	11	16	
....	....	167	10	3	8	8	
....	....	203	1	2	.....	3	
....	....	203	1	3	.....	5	
....	....	203	1	1	.....	2	
....	....	150	1 to 3	1 to 4	2 to 3	4 to 15	
Wood's....	May be used for soldering in hot water.	140 to 161.5	1 to 2	2	4	5 to 8	Platinum color, somewhat malle- able.
	do.	179.5	1	.....	6	7	
	Soft solder.	300	2	4	2	.....	Melting point 86° below that of a lead-tin alloy.
Cliché metal.	For clichés.	.....	22½	36	50	.....	Melting point as low as cliché metals of bis- muth alloys, and is harder.

According to Hauer, the melting points of fusible alloys are proportionate to the atomic composition, thus:

Formula	Melting point, ° F.	Formula	Melting point, ° F.
(1) CdSnPbBi	155.1	(4) CdPb ₆ Bi ₇	190.4
(2) Cd ₃ Sn ₄ Pb ₄ Bi ₂	153.5	(5) CdPb ₃ Bi ₂	193.0
(3) Cd ₄ Sn ₅ Pb ₅ Bi ₅	150.0	(6) Cd ₂ Pb ₇ Bi ₄	203.0

The above formulas correspond to the following percentage compositions:

Compositions of above formulas

	(1)	(2)	(3)	(4)	(5)	(6)
Cadmium.....	17.31	13.6	14.3	4.0	9.7	8.9
Tin.....	18.24	19.0	16.0			
Lead.....	32.00	33.4	33.1	44.0	54.0	57.7
Bismuth.....	32.45	34.0	36.6	52.0	36.3	33.4

It is sometimes claimed that cadmium alloys are not constant as to their melting points, and that on account of the volatility of cadmium, the alloy will fuse with greater difficulty the more often it is re-melted. A glance at the above figures shows plainly that cadmium cannot volatilize at these temperatures; and, further, a series of experiments made especially for the purpose has shown that the alloys can be melted as often as desired without their melting points being sensibly changed. It may, however, happen that the alloys, originally homogeneous, may by liquation separate into several alloys with different melting points, if a large quantity of it be allowed to stand in a molten state for a long time. This can, however, be readily prevented by not keeping the alloy in a liquid state until this liquation takes place, which requires many hours, and if it does take place, by vigorous stirring of the melted alloy.

The alloys of cadmium with mercury (cadmium amalgams) have been discussed under amalgams, and those containing gold, which for certain purposes are used by goldsmiths, will be mentioned under gold alloys.

BISMUTH

Like cadmium, bismuth possesses the property of lowering the melting points of metals, and is therefore frequently used in the preparation of fusible alloys, which would be still more extensively used if bismuth could be obtained in abundance and at a small cost. The alloys are now chiefly used in the preparation of delicate clichés, very fusible solders, and in the manufacture of safety-valves of a peculiar construction for steam boilers.

The behavior of bismuth towards other metals is stated by Guettier as follows:

Bismuth and copper.—These alloys are easily effected notwithstanding the difference in the points of fusion of the two metals. They are brittle and of a pale-red color whatever the proportions employed. Their specific gravity is sensibly equal to the average of the two metals.

Bismuth and zinc.—These alloys are seldom made, and produce a metal more brittle, presenting a large crystallization with less adherence than zinc or bismuth taken singly, and on that account they are useless in the arts.

Bismuth and tin.—These combinations take place easily and in all proportions. A very small quantity of bismuth imparts to tin additional hardness, sonorousness, luster, and fusibility. On that account, and for certain applications, a little bismuth is added to tin to increase its hardness. However, bismuth being easily oxidized and often containing arsenic, the alloys of tin and bismuth would be dangerous for the manufacture of domestic utensils.

The alloys of tin and bismuth are more fusible than each of the metals taken separately. An alloy of equal parts of the two metals is fusible between 212 and 302° F. When tin is alloyed with as little as 5% of bismuth, its oxide acquires the peculiar yellowish-gray color of the bismuth oxide. According to Rudberg, molten bismuth begins to solidify at 507° F., and tin at 550° F.; while for the alloys of the two metals the constant point is 289° F.

Bismuth and lead.—These two metals are immediately alloyed by simple fusion with merely the ordinary precautions. The alloys are malleable and ductile as long as the proportion of bismuth does not exceed that of lead. Their fracture is lamellar, and their specific gravity is greater than the mean specific gravity of either metal taken singly. An alloy of equal parts of bismuth and lead has a specific gravity of 10.71. It is white, lustrous, sensibly harder than lead, and more malleable. The ductility and malleability diminish with an increased proportion of bismuth, while they increase with the excess of lead in the alloy. An alloy of 1 part bismuth and 2 parts lead is very ductile, and may be laminated into thin sheets without cracks. According to Berthier its point of fusion is 331° F.

Bismuth and iron.—Authorities disagree as to the possibility of combining bismuth and iron, the presence of bismuth in iron rendering the metal brittle.

It will be seen, from the preceding data, that the alloys of bismuth are not at present of importance in the arts excepting the fusible alloys made of bismuth and certain white metals, such as tin, lead, and a few others.

Bismuth and antimony.—The alloys of these two metals alone are grayish, brittle, and lamellar. In order to remove the brittleness, varying quantities of tin and lead are added, whereby their fusibility rather increases than decreases. Alloys containing the above metals are much used in the preparation of Britannia and Queen's metals, but they are also employed for some special purposes of which the following are examples:

Cliché metal.—This alloy is composed of 48 parts of tin, 32.5 parts of lead, 9 parts of bismuth, and 10.5 parts of antimony. It is especially suitable for "dabbing" rollers for printing cotton goods; and, possessing a considerable degree of hardness, it wears well.

For filling out defective places in metallic castings the following alloy can be used to advantage: Bismuth, 1 part; antimony, 3 parts; and lead, 8 parts.

Bismuth, tin, and lead.—The compounds obtained by alloy-

ing these metals have a somewhat higher melting point than the cadmium alloys. They have, however, been known for a long time, and are used for various purposes.

Newton's metal consists of 8 parts bismuth, 5 parts lead, and 3 parts tin. It melts at 202° F.

Rose's alloys consist of 2 to 8 parts bismuth, 1 to 3 parts tin, and 1 to 8 parts lead.

The first of these alloys melts at 200.75° F., and the other at 174.20° F. These alloys were formerly used in the preparation of the so-called safety-plates which were inserted in the tops of steam boilers. The composition of these plates was such that they became fluid at a determined temperature corresponding to a certain steam pressure in the boiler, thus giving the steam a chance to escape through the aperture formed. Such plates acted as a sort of safety-valve, and were intended to prevent the explosion of the boiler with too high a tension of steam. Their use has, however, been almost entirely abandoned, it having been found that boilers provided with these plates would explode without a previous melting of the plates. A chemical and physical examination has shown that by long-continued heating of the plates, alloys are formed whose melting points are much higher than those of the compositions originally used. The following table gives the compositions of some alloys which are said to melt, if the pressure of the steam exceeds that indicated:

TABLE 65.—*Composition and melting point of certain alloys and corresponding steam pressure*

Bismuth	Lead	Tin	Melting point, ° F.	Corresponding pressure of steam in pounds
8	5	3	212	15
8	8	4	235.9	22½
8	8	8	253.9	30
8	10	8	266	37½
8	12	8	270.3	45
8	16	14	289.5	52½
8	16	12	300.6	60
8	22	24	308.8	75
8	32	36	320.3	90
8	32	28	331.7	105
8	30	24	341.6	120

Onion's fusible alloy consists of 3 parts lead, 2 parts tin, and 5 parts bismuth. It melts at 197° F.

D'Arcet gives the following proportions for fusible alloys:

TABLE 66.—*Mixtures for fusible alloys*

No.	Bismuth	Lead	Tin	Remarks
1	7	2	4	Softens at 212° F., without melting.
2	8	2	6	Softens at 212°, easily oxidized.
3	8	2	4	Softens more or less at 212°. No 4 becoming softer than either No. 3 or No. 5.
4	16	4	7	
5	9	2	4	
6	16	5	7	Becomes nearly fluid at 212°.
7	8	3	4	Becomes quite liquid at 212°.
8	8	4	4	Becomes very liquid at 212°.
9	8	7	1	Becomes soft at 212° F., but does not melt.
10	16	15	1	Neither liquid nor soft at 212°.
11	8	5	3	Melts at 205°.
12	8	6	2	Melts at 205°.
13	16	9	7	Becomes very liquid at 212°.

These alloys are generally hard, but may be cut. Their fracture is a dead blackish-gray. They are rapidly tarnished in the air, and more so in boiling water, in which they become covered with a wrinkled pellicle which falls as a black powder.

Lichtenberg's metal consists of 5 parts bismuth, 3 parts lead, and 2 parts tin; and melts at 197° F.

Bismuth alloys for fine castings.—For the preparation of castings of delicate articles, and taking impressions from dies, medals, etc., bismuth alloys of the following composition (parts) have been recommended:

Composition of bismuth casting alloys

Bismuth.....	6	5	2	8
Tin.....	3	2	1	3
Lead.....	13	3	1	5

These alloys expand strongly on cooling, so consequently fill out the finest depressions and elevations.

Bismuth alloy for cementing glass.—Most cements are dissolved by petroleum, or, at least, softened by it. The following alloy, which melts at 212° F., is, however, not

attacked by petroleum, and is therefore well adapted for fastening metal parts on glass lamps: lead, 3 parts; tin, 2 parts; and bismuth, 2.5 parts.

The following table, Parkes and Martin, indicates the various points of fusion of the fusible combinations of bismuth, lead, and tin:

TABLE 67.—*Fusing points of bismuth-lead-tin combinations*
(Parkes and Martin)

Bismuth	Lead	Tin	Temperature of fusion, ° F.	Bismuth	Lead	Tin	Temperature of fusion ° F.
8	5	3	202	8	16	24	316
8	6	3	208	8	18	24	312
8	8	3	226	8	20	24	310
8	8	4	236	8	22	24	308
8	8	6	243	8	24	24	310
8	8	8	254	8	26	24	320
8	10	8	266	8	28	24	330
8	12	8	270	8	30	24	342
8	16	8	300	8	32	24	352
8	16	10	304	8	32	28	332
8	16	12	294	8	32	30	328
8	16	14	290	8	32	32	320
8	16	16	292	8	32	34	318
8	16	18	298	8	32	36	320
8	16	20	304	8	32	38	322
8	16	22	312	8	32	40	324

Grinnell sprinkler.—One of the largest makers of fusible alloys is the General Fire Extinguisher Co. of Providence, Rhode Island, which specializes on the Grinnell sprinkler, now so well known. What is termed the 155-degree head constitutes the vital part of this sprinkler. The composition is 50% bismuth, 25% lead, 13% cadmium, and 12% tin; and its melting point is 162° F. Reference to figure 86 will make clearer the following description of its operation:

Yoke *A* and body *B* in view—both bronze castings—are screwed together as shown in 2 with a flexible metal diaphragm *C* clamped between them. A soft metal seat, on which rests the glass valve *E*, surrounds a ½-inch orifice in the center of the diaphragm. This valve is held to its seat by a strut consisting of three pieces, namely, the main strut piece *F*,

hook *G*, and key *H*. These pieces are made of a non-corrosive nickel alloy, and are held together by the fusible alloy given above. Hook *G* and key *H* act as levers, and their arrangement is such that only a very moderate stress is set up in the solder, thus ensuring tightness of the sprinkler under heavy

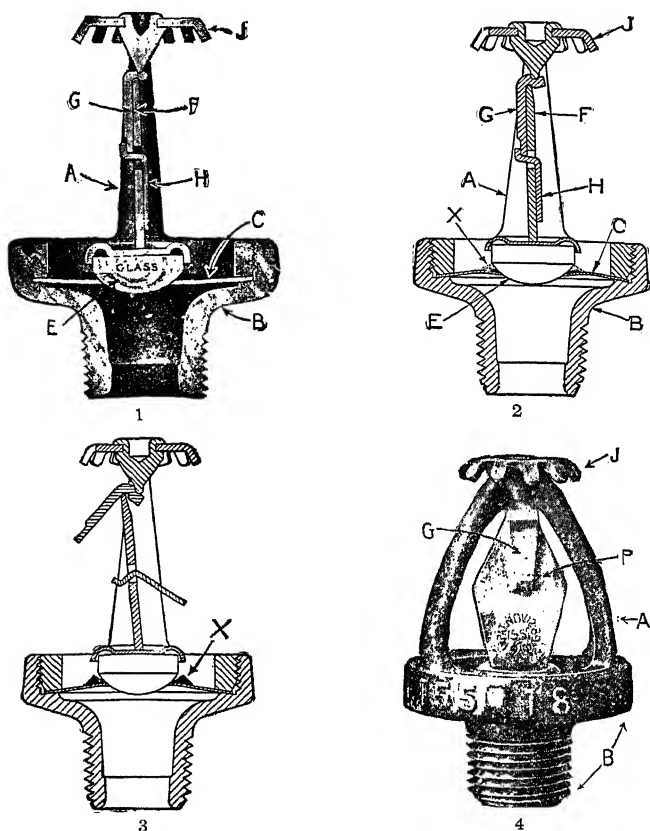


Figure 86.—Four views of automatic sprinkler.

water pressure. The diaphragm *C* also materially assists in preventing leakage past *E*, for the greater the water pressure the greater the force with which the soft metal seat is pressed against the valve.

When the heat from the fire has melted the solder, the hook *G* and key *H* rock about their respective fulcrums, as in

4, allowing the water to force the glass valve *E* from its seat and throw the parts of the strut from its path. A solid $\frac{1}{2}$ -inch stream then impinges upon deflector *J*, and the water is thus scattered in every direction. While the parts of the strut are separating, the diaphragm *C* forcibly follows valve *E* in its upward movement for a sufficient distance to ensure the complete separation of the soldered parts before any water issues from the sprinkler. The operating parts of the strut do not slide one upon the other, but merely rock about fulcrums. This rocking is materially aided by the presence of the melted solder, which acts as a lubricant, and in addition prevents corrosion from sticking the parts together.

It sometimes happens that a deposit of foreign matter, represented by *X* in 3, lodges around the glass valve *E*. The upward movement of the diaphragm during the operation of the sprinkler materially assists in freeing the glass valve from this deposit, as shown in 4.

It is recommended that no steam-heating pipe be placed nearer than 2 feet to any sprinkler head; that they should not be painted as this makes them slow to operate; and that although under ordinary conditions sprinkler heads last indefinitely, the metals in them are subject to more or less chemical influences, which tend to deterioration, so to be sure of the fire system, every 10 years or so some of the heads should be examined for possible corrosive influences.

Experience has proved that it is good practice to allow a margin of approximately 60° in temperature between the operating point of the sprinkler head and the maximum temperature of the room where the sprinkler is installed. For instance, 155-degree heads (uncolored) when the room temperature is below 100; 212-degree heads (color white) when maximum temperature of room is between 100 and 150; 286-degree heads (color blue) when maximum temperature of room is between 150 and 225° ; 360-degree heads (color red) when maximum room temperature is between 225 and 300° . The composition of the 155-degree head has been given; the 212-degree consists of 50% bismuth, 31% lead, and 19% tin;

the 286-degree, 50% each of bismuth and tin; while the 360-degree contains 66.6% tin and 33.3% lead.

Bismuth alloys are suitable baths for tempering small steel tools. They give a very exact temperature, which may be adjusted to the purpose intended. They are used, according to Thurston,* by placing the article on the surface of the unmelted alloy, and gradually heating until fusion occurs and they fall below the surface, at which moment their temperature is right; they are then removed and quickly cooled in water. It is not easy, even if possible at all, to give as uniform a temperature by the ordinary processes of heating or to obtain the exact heat desired, and the quality of the tool is not so easy of adjustment by any other method.

Alloys of lead and bismuth have also been tried, but they are too easily oxidized, and are difficult to make on account of the separation of the lead. An alloy of equal parts of bismuth and lead possesses a toughness from 15 to 20 times that of lead. Alloys of bismuth and tin are better, the best known being the 50-50 alloy, melting at 310° F.; the 33-67 alloy, melting at 325°; and the 20-80 alloy, melting at 480° F. The first mentioned is called "cutlanego," and its oxide makes a white enamel.

Very fusible alloy.—This alloy, which is suitable for many applications in the arts, is composed of 48 parts bismuth, 13 parts cadmium, 19 parts lead, and 26 parts tin. It melts at about 158° F., and, consequently, at a lower temperature than that at which the so-called "magic spoon" melts in a cup of tea. It is said to resist great pressure.

* Brasses, Bronzes and other Alloys, p. 196.

CHAPTER XXIII

IRON ALLOYS

PURE iron is a difficult metal to obtain because it has great affinity for nearly all other elements from which it is only isolated at considerable trouble and expense. Commercial iron and steel will contain from 96.00 to 99.60% of iron, and is made from pig iron, which in turn is obtained from the ore by a process carried out in blast-furnaces. Pig iron, also known as cast iron, is an alloy of iron with various metals and metalloids, its most important constituent being carbon.

DEFINITIONS

The following definitions of the most important forms of iron and steel were adopted at the Brussels Congress of the International Association for Testing Materials, in September, 1906:

Alloy cast irons.—Irons which chiefly owe their properties to other elements than carbon.

Alloy steels.—Steels which owe their properties chiefly to the presence of another element than carbon.

Basic pig iron.—Pig iron containing so little silicon and sulphur that it is suited for easy conversion to steel by the basic open-hearth process; this is restricted to pig iron containing not more than 1.00% of silicon.

Bessemer pig iron.—Iron containing so little phosphorus and sulphur that it can be converted into steel by the original or acid process using the Bessemer converter; this is restricted to iron containing not more than 0.10% phosphorus.

Bessemer steel.—Steel made by the Bessemer process, irrespective of its carbon content.

Blister steel.—Steel made by carburizing wrought iron by heating it in contact with carbon.

Cast iron.—Iron that contains so much carbon or its equivalent

that it is not malleable at any temperature. The Committee suggested that 2.20% carbon should be the dividing line between cast iron and steel.

Cast steel.—The same as crucible steel; obsolete and confusing, the terms “crucible steel” or “tool steel” are to be preferred.

Converted steel.—The same as blister steel.

Charcoal hearth cast iron.—Cast iron from which the silicon content, and usually the phosphorus also, has been removed in the charcoal hearth, but which will still contain sufficient carbon to be distinctly a cast iron.

Crucible steel.—Steel made by the crucible process, irrespective of its carbon content.

Gray pig iron and gray cast iron.—Pig iron and cast iron in the fracture of which the iron itself is nearly or quite concealed by graphite, so that the fracture has the gray color of graphite.

Malleable castings.—Castings made from iron known as cast iron, and which is made malleable afterwards by an annealing process without fusion.

Malleable iron.—The same as wrought iron.

Malleable pig iron.—An American trade name for the pig iron suitable for making malleable castings through the process of melting, casting, and annealing the castings.

Open-hearth steel.—Steel made by the open-hearth process, irrespective of its carbon content.

Pig iron.—Cast iron that has been cast into pigs directly from the blast-furnace.

Puddled iron.—Wrought iron made by the puddling process.

Puddled steel.—Steel made by the puddling process and necessarily carrying slag.

Refined cast iron.—Cast iron which has had most of its silicon removed in the refinery furnace, but still contains so much carbon as to be distinctly cast iron.

Shear steel.—Steel, usually in the form of bars, made from blister steel by shearing it into short lengths, piling, and welding these by rolling or hammering them at a welding heat. If this process of shearing is repeated, also the welding, the product is known as “double-shear steel.”

Steel.—Iron, which is malleable, at least in some one range of temperature, and, in addition, is initially malleable when cast, or capable of hardening by sudden cooling, or which is not only malleable when cast, but may also be hardened.

Steel castings.—Unforged and unrolled castings made of Bessemer, open-hearth, crucible, or any other steel.

Washed metal.—Cast iron from which most of the silicon and phosphorus have been removed by the Bell-Krupp process without removing much of the carbon, and therefore still containing sufficient carbon to be termed “cast iron.”

Weld iron.—The same as wrought iron; obsolete and needless.

White pig iron and white cast iron.—Pig iron and cast iron in the fracture of which little or no graphite is visible, the fracture being thus silvery and white.

Wrought iron.—Slag-bearing malleable iron which does not harden materially when suddenly cooled.

Cast iron is almost universally used for shapes formed by pouring the molten metal into molds. Its melting point is about 2300° F. It is not suitable for parts subjected to shock and strain, as it is brittle and weak in tension. Its specific gravity is 7.21, and weighs 0.260 lb. per cu. in., or 464 lb. per cu. ft. Its compressive strength is about 95,000 lb. per sq. in.; tensile strength, 16,000 to 17,000 lb. per sq. in.; and shear, 20,000 lb. per sq. in.

FOUNDRIY IRONS

Iron castings are affected by five elements associated with the iron, namely, carbon, silicon, manganese, phosphorus, and sulphur. Carbon is contained in iron in two forms, as combined carbon and graphitic or free carbon. The total carbon content of cast iron may run from 3.5 to 4%. Both kinds of carbon may be present in the iron in varying proportions—for instance, for light castings the proportion of combined to graphitic carbon should be 1 to 10. If graphitic carbon should predominate excessively, large castings would be weak. The ability of carbon to combine with iron is affected by silicon and manganese, also slightly by sulphur. Combined carbon adds strength and hardness to castings.

Silicon.—This element is very important in foundry irons. When under 2.5%, its tendency is to cause the carbon to separate out as graphite, giving the castings the desired benefits of graphitic carbon. For iron carrying a fair proportion of low silicon scrap, and dense iron from 2.5 to 3.5% of silicon is best adapted, for ordinarily no mixture should run below 1.5% silicon to get good castings. From 1.5 to 2% of silicon is best adapted for machine work, and will produce strong, clean castings, provided little scrap is used with it.

Excessive silicon decreases strength and produces brittleness. Strongest castings are made from iron which will produce sound castings with the least amount of silicon. The loss of silicon in re-melting can be figured at about 0.25%.

Manganese.—This element causes hardness and shrinkage, and acts directly on the iron. Its tendency is to maintain the carbon in the combined state, also to remove sulphur. The loss of manganese during melting is generally figured at 0.10%.

Phosphorus.—When high, this element has a tendency to make the iron fluid, and it will retain its heat longer. It also reduces shrinkage, but when excessive it causes "cold shuts." It should never exceed 0.75%, and is not lost during melting.

Sulphur.—This element makes the iron hard and white (red-short) by causing it to retain its carbon in a combined state. It also makes for sluggish iron and gives rise to blow-holes on solidification. The red-shortness caused by sulphur can be counteracted by manganese. Sulphur should never exceed 0.10% in castings. Irons with above 1% manganese seldom contain any sulphur of consequence. Actual practice shows that about 0.03% of sulphur is absorbed by the iron during melting. Lime or fluorspar used as a flux will assist in the removal of sulphur. Some foundry iron mixtures are given in the following table:

Analysis of foundry machine irons for light castings

No.	Silicon, %	Phosphorus, %	Manganese, %	Sulphur, %	Remarks
1	3.20	1.00	0.45	0.08	Very satisfactory for light work in general.
2	2.80	0.49	0.61	0.015	A Southern brand noted for fine machine castings.
3	3.26	0.42	0.25	0.03	A Pennsylvania iron, soft and strong, with no shrinkage.
4	2.66	0.77	1.20	0.02	Noted Ohio brand, very fluid and strong; does not shrink.

Analysis of foundry machine irons for medium work

No.	Silicon, %	Phos- phorus, %	Man- ganese, %	Sulphur, %	Remarks
1	2.12	0.61	0.80	0.02	Strong and soft, makes clean, solid castings; easily machined.
2	2.10	0.41	0.60	0.05	A soft and fluid mixture.

Analysis of foundry machine iron for heavy work

(Good agricultural scrap alone can be used with good results)

No.	Silicon, %	Phos- phorus, %	Man- ganese, %	Sulphur, %	Remarks
1	1.30	0.26	0.70	0.03	Southern brand; very good for heavy work.

For fine castings demanding elegance of design but no strength, phosphorus up to 3.0% is good. It can also stand 1.5 to 2.0% of manganese.

In calculating mixtures it is rather difficult to ascertain with any degree of certainty the chemical analysis of scrap iron, but one of 1.70% silicon, 1.00% phosphorus, 0.60% manganese, and 0.10% sulphur has been found to give satisfactory results when used in making up a charge. Stove-plate scrap is generally low in manganese, high in sulphur, and runs about 2.75% silicon.

Blast.—The volume of blast to melt a ton of iron in the cupola—that is, for 250 lb. of coke—is about 25,000 to 30,000 cubic feet, and the most economical pressure is about 12 oz.

Melting cast iron.—Cast iron is usually melted in the cupola furnace, which is a miniature blast-furnace, and the iron, fuel, and blast all come into contact. It consists of a tubular boiler-iron shell set vertically on legs and fitted with a cast-iron bottom, hinged and in two parts, and adapted either to be securely fitted in place as a bottom or to fall away like a trap-door, and thus permit the residue (clinker, slag,

etc.) from melting operations to be dumped. The shaft is lined with firebrick. There is an opening at the bottom connecting to a spout from which the liquid iron can be tapped at will. The fire is urged by a blast admitted into the cupola by a wind-box which encircles the furnace near the bottom. Cupolas extend upwards two stories as a general rule, the upper of which is the charging floor, where there is an opening into the cupola shaft. In starting the furnace, the bottom is securely propped up in place and a sand bottom is rammed on it inside. This bottom is sloped gently towards the tap-hole so the molten iron will run out when the hole is opened.

The tap-hole is made up every day, and at this point there is a considerable hole in the furnace shell, which is built up by the cupola tender, leaving the round hole at the bottom, from which the iron will run. This is called the breast of the cupola, and after it is made up, the tap-hole is left open, and a fire is started on the hearth—generally by using kindling and coke—which is done while the tap-hole and breast are being made. The air to support combustion enters through the tap-hole opening and through the peep-holes. As the pressure of the molten iron comes against the breast, this opening has to be closed by a strong wall. A wooden plug is often used as a pattern to form the tap-hole, and this is first laid in place in line with the sloping sand bottom, then the opening is filled with small pieces of coke, which are wedged together to form a wall, and then is plastered up with clay and sand. The first charge of coke is called the “bed,” and the correct thickness of this is a matter of great importance for the proper melting of the iron; if the bed is too thin and there is not enough coke the iron will come down cold, and many castings will be “lost” because they did not run up properly, or had other defects due to cold metal.

To get the correct height of the coke bed, a measuring stick is lowered to the surface of the bed from the charging door, and this height has to be carefully calculated for each individual case. The first charge of iron is put on top of the bed, and on that another charge of coke, then iron, next

coke, and so on alternately until the cupola is filled to the charging door. The proper proportion of coke to metal is very important, and must be figured out; usually the ratio of iron to coke is 10 to 1, and as, according to Moldenke, experience has shown that each layer of coke must be 4 inches in thickness, to get the weights of the charges of coke and iron it is only necessary to measure the diameter of the cupola, then build a ring of lining bricks to a circle the diameter of the cupola and 4 inches high, then fill it with coke. If it is more convenient to make the ring of bricks one foot high, this is done, and when filled with coke and weighed the result must be divided by three, which gives the weight of 4 inches of coke in that particular cupola. To get the metal charge multiply the weight of the coke by 10. If the coke weighs 200 lb., the metal charge will be 2000 lb. A little adjusting of coke charges will probably be necessary, the factors to be watched being the temperature of the molten iron and the speed of melting. The molten iron is run into a large ladle, from which it is emptied into the smaller ones used to carry the metal to the molds.

Electric furnace.—The electric furnace is also used to some extent for making castings of cast iron, and probably this development is due to the use of the electric furnace for using up the large amount of steel turnings from war material. This was melted and re-carburized in an electric furnace, and the product is known as synthetic cast iron. It is a very strong cast iron. A furnace such as shown on figure 87 is suitable. The mechanism underneath the furnace is of the electrically driven tilting type.

Semi-steel castings.—This material is a good grade of cast iron made by the addition of about 25% of steel scrap to the cast iron in the cupola. The castings are close-grained and easy to machine. The specific gravity will be 7.7; melting point, 2650° F., tensile strength, about 30,000 lb. per sq. in.; compressive strength, about 40,000 lb. per sq. in.; shear, 30,000 lb. per sq. in.; and weight, 0.270 lb. per cu. in.; or 470 lb. per cu. ft.

Duriron.—This is an acid-resisting material containing about 12% of silicon. It is hard and brittle, and is used for parts that come into contact with acids in the manufacture of chemicals. Its specific gravity is 7.0; tensile strength, 13,000 lb. per sq. in.; and melting point, about 2190° F.

Malleable iron.—This iron is not “malleable” when first made as castings; its ductility comes as a result of a prolonged

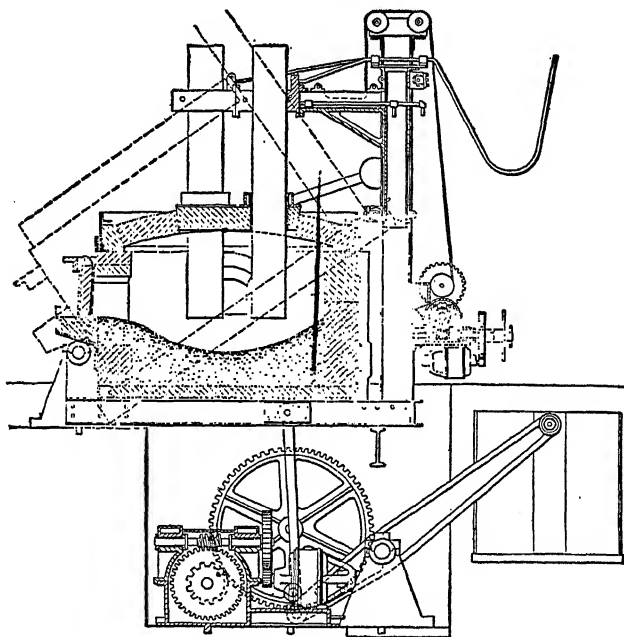


Figure 87.—Heroult electric furnace.

heat-treatment of the castings. When taken from the sand in which they were cast, the castings are white, hard, and brittle; more so than ordinary cast-iron castings, because a special iron is used—an iron in which the carbon exists—chemically combined. The properties of any ferrous alloy, such as cast iron, malleable iron, carbon steels, etc., depend upon the quantity and the condition (whether chemically combined or merely held in suspension) of the carbon contained therein. The carbon can be simply mixed in with the iron,

existing as flakes of graphite; then again the carbon can be dissolved in the iron, like sugar in water. When dissolved, the carbon has united with the iron to form iron carbide, and as this product is an extremely hard substance, the iron containing it is also hard. As we are not going to deal extensively with the iron alloys, it will not be considered necessary to discuss the reason why a "white iron"—as the iron containing combined carbon is called—is best for making castings which have to be annealed to malleable castings. The white iron used for castings will have about the following analysis:

Analysis of white iron

	Per cent
Carbon.....	2.30 to 3.20
Manganese.....	0.035
Silicon.....	1.080 to 0.50
Phosphorus.....	0.225
Sulphur.....	0.010

When cast, this white iron shrinks twice as much as soft cast iron or $\frac{1}{4}$ inch per foot—which causes much trouble from shrinkage cracks, especially when large cores are used. Naturally, the cores have to be porous and soft so they will give to the iron. The castings are cleaned and then packed in iron boxes called annealing boxes, or iron pots as they are also termed. These pots are 18 inches wide, 24 inches long, and 15 inches high, and will last from 6 to 10 heats apiece. As these boxes have to withstand heat we will give their composition. as used by one firm:

Annealing boxes—cupola mixture (as charged)

	Per cent
Malleable scrap.....	60
Gray iron scrap.....	20
Steel scrap.....	20

The castings are embedded in rolling-mill scale as a rule, though common sand has been used with just as good results. The boxes are packed three high in a large oven, which is sealed and then heated as rapidly as possible to a temperature of 1400 to 1700° F. The oven is maintained at this temperature for 48 hours, then the fire is allowed to die out, and

the oven cools for 4 days. When the cooling oven reaches a temperature of 1400° F., the rate of cooling is carefully regulated in order that it shall not be faster than 6° per hour to get the best results.

This annealing changes the iron in the castings; they lose in carbon and gain in sulphur, the latter being absorbed from the packing and fuel. The castings also change in volume while annealing, they swell $\frac{1}{8}$ inch to the foot, thereby recovering one-half of the shrinkage at casting. The castings are rendered ductile by this annealing and will have from 6 to 15% elongation. This is malleable iron.

Cast iron.—There are many different analyses of cast iron. It will vary in its carbon content, also and in the manner in which the carbon exists in the iron, which has an important effect on the properties of the iron. The white iron used for making malleable iron, which contains much carbon dissolved or combined with the iron, expands when heated in the annealing oven. Such an iron will expand when cast into ingot molds for receiving brass because it will then be repeatedly heated and cooled. This expansion of the iron will bulge out the sides of the molds and produce cracks into which the brass will run making it difficult to free the ingot after it has set. For ingot molds, furnace plates, furnace covers, and furnace flues, it is best to specify a soft gray iron because the greater part of the carbon in such an iron is in the graphitic state; and the castings will be less likely to grow upon repeated heating and cooling.

The following analysis of an ideal heat-resisting cast iron will be given, in case the brass foundry desires to make the castings for such parts:

Analysis of heat-resisting cast iron

	Per cent
Combined carbon.....	0.30
Total carbon.....	3.30
Graphitic carbon.....	3.00
Manganese.....	0.75
Silicon.....	2.15
Phosphorus.....	0.30
Sulphur.....	0.06
Iron.....	93.14

Ferro-alloys are alloys of iron high in some other element such as ferro-silicon, ferro-manganese, ferro-chrome, etc., and are used in modern steel making and iron melting to add definite amounts of various elements to iron or steel.

For the foundryman who is not well versed in the subject of the ferro-alloys, he would profit by studying the paper * "The Ferro-Alloys," read by the late J. W. Richards at the Fourth National Exposition of Chemical Industries at New York City on Sept. 27, 1918. This was a brief description of the manufacture, properties, and uses of the alloys of iron with aluminum, boron, chromium, manganese, molybdenum, silicon, titanium, tungsten, uranium, and vanadium. They were originally made in crucibles, cupolas, or blast-furnaces, but are now made principally in electric furnaces. They are of great importance—in fact, indispensable—to the steel industry, either in the making of ordinary steel or for producing special alloy steels.

Electric furnaces for ferro-alloys.—The following excerpts touch briefly on this subject:

The manufacture of ferro-alloys in the electric furnace was fully discussed by R. M. Keeney in a paper † read before the Colorado meeting of the American Institute of Mining Engineers in September, 1918. Prior to 1914 there was only one electric-furnace plant west of the Mississippi, and that was reducing pig iron in California; and all molybdenum, tungsten, uranium, and vanadium concentrates were shipped to the Eastern States for reduction. Furnace charges, reactions, and analyses of products were given in detail. The metallurgical problems encountered in the manufacture of ferro-alloys have been the production of an alloy with a low percentage of carbon, a high percentage of the alloying element, and a low percentage of impurities such as phosphorus and sulphur, which might be injurious to the steel. The alloy

* *Chem. and Met. Eng.*, vol. 19, 1918, p. 501.

† *Transactions A. I. M. E.*, vol. 62, 1920, p. 28.

should have a melting point low enough to be used in a steel bath of ordinary temperature.

At the April, 1921, meeting of the American Electrochemical Society, H. W. Gillett presented a paper entitled "Electric Furnaces for non-Ferrous Metals." There were at that time in this country a total of 318 electric furnaces operated at 169 plants, with a total capacity per heat of 193 tons. There were another 70 furnaces projected. Tables 69 is a summary of the applicability of various types of electric furnaces to various alloys.

Ferro-chrome.—According to Robert M. Keeney, this alloy is made from domestic chromite ore by mixing the ore with coal or coke, lime, fluorspar, or silica in proper proportions, and smelting the mixture in an electric furnace. At 2-hour intervals the ferro-chrome and slag are tapped into iron pots, the metal settling to the bottom. The pot is dumped when the contents are solidified.

Ferro-chrome varies in its carbon content, and the following are analyses of the alloy made from domestic ores:

TABLE 68.—*Analyses of ferro-chrome (Keeney)*

	Carbon, 1% max.	Carbon, 2% max.	Carbon, 5% max.	Carbon, 6% max.	Carbon, 7% max.	Carbon, 8% max.
Carbon.....	0.75	1.83	4.75	5.52	7.00	7.67
Chromium.....	67.20	62.10	63.40	65.00	66.00	66.40
Silicon.....	0.42	0.40	0.17	0.47	0.93	0.86
Manganese.....	.....	0.14	0.25	0.29	0.24	0.27
Sulphur.....	0.052	0.056	0.082	0.078	0.055	0.056
Phosphorus.....	0.062	0.047	0.045	0.036	0.035	0.036

Ferro-manganese.—This alloy is made in the electric furnace and in the blast-furnace. The charge consists of ore, coal, and limestone in proper proportions. The electric furnace will operate at from 75 to 100 volts. Standard ferro-manganese is only guaranteed to carry 80% or over of manganese. The British alloys run lower in phosphorus than some brands. Some of the domestic manganese ores mined in Colorado, Utah, and Nevada are so high in phosphorus that they must be mixed with low phosphorus ore to yield a product

TABLE 69.—*Applicability of various types of electric furnaces to various alloys*

Alloy analysis							Types of furnaces								
Fe	Cr	Ni	Cu	Sn	Pb	Zn	Ag	Al	Direct arc	Stationary indirect arc	Moving indirect arc	Re-flected heat	Contact resistance (Bennett)	Vertical ring induction	High frequency
..	15	85	..	..	..	..	..	..	O.K.	O.K.	O.K.?	? ¹	?	?	O.K.?
5	..	67	28	..	..	..	..	..	O.K.	O.K.	O.K.	? ¹	?	?	O.K.?
		{ 25	75	..	..	..	..	..	?²	O.K.	O.K.	O.K.	O.K.?	?	O.K.?
		{ 5	95	..	..	..	..	..	?²	O.K.	O.K.	O.K.	O.K.	No ³	O.K.
			100	..	..	..	..	..	O.K.	O.K.	O.K.	O.K.	O.K.?	? ³	O.K.
			{ 90	10	..	..	..	..			
			{ 88	10	2	..	..	..				
			{ 80	10	10	3	..	..	O.K. ⁵	O.K.	O.K.	O.K.	O.K.?	No ⁴	O.K.
			{ 76	3	18	2	..	..	No ⁵	O.K.	O.K.	O.K.	O.K.	O.K.	O.K.
			{ 68	4	26	5	..	..					
			85	5	5	17	..	..					
			{ 74	4	5	20	..	..					
			{ 80	..	..	30	..	..	No ⁵	No ⁵	O.K.	O.K.	O.K.	O.K.	O.K.
			{ 70	..	..	30	..	..					
			{ 67	..	3	38	..	..					
			{ 61	1	..	34	..	..					
			{ 65	..	..	40	..	..					
			{ 60	..	..	24	..	..	No ⁵	No ⁵	O.K.	O.K.	?	O.K.	O.K.
		18	58	..	..	15	..	85	No ⁵	? ⁵	O.K.	O.K.	?	? ³	O.K.
			{ 3	..	..	30	..	68							
			{ 2	..	..	..	..	92	?	O.K.?	O.K.	O.K.	?	? ³	O.K.
			8	..	..	..	..	..	?⁵	O.K.	O.K.?	O.K.?	?	? ³	O.K.
			10	..	..	..	90	..	No	No ⁵	O.K.?	O.K.	?	?	O.K.?
			10	..	..	85	..	5							

O.K. = Furnace metallurgically satisfactory for this alloy.

? = No data on hand.

O.K. = Probably satisfactory, but no record of trial.

No = Furnace not satisfactory for this alloy.

¹ Temperatures probably rather high for good refractory life.² Question of copper poisoning by fume from direct arc not yet settled.³ Induction furnace on this alloy would require resistor tube of special design.⁴ Lead too high for good life of usual lining of induction furnace.⁵ Furnace causes loss of volatile metal from this alloy.

under 0.2% phosphorus. An analysis of British ferro-manganese follows:

Analysis of British ferro-manganese

	Per cent
Manganese.....	80.50
Iron (by difference).....	11.50
Silicon.....	1.65
Phosphorus.....	0.23
Carbon.....	6.78

The high carbon indicates that carbides of manganese and iron comprise part of the alloy. When ferro-manganese is added to copper or to copper alloys, as in making manganese copper, using ferro-manganese there is a great loss of metal due to the rejection of the carbides by the copper.

Silico-spiegel.—This alloy contains 17 to 22% manganese, and 6 to 12% silicon. The standard is guaranteed as follows: Manganese, 18 to 20%; and silicon, 9 to 11%—average 10%.

Ferro-manganese silicon.—According to Keeney, three grades of ferro-manganese silicon are made, as follows: 50 to 55% manganese, and 23 to 28% silicon; 68 to 75% manganese, and 20 to 25% silicon; and 50 to 55% manganese, and 30 to 35% silicon. The carbon content in these alloys is low, owing to the action of silicon breaking up the combined carbon in the ferro-manganese, causing the carbon to separate as graphite, which rises to the surface of the molten metal. With less than 16 to 18% of silicon in the alloy, carbon remains in the combined state, but with more than the percentage, any carbon present is in the form of graphite. Analyses of typical silico-manganese follow:

TABLE 70—*Analyses of typical ferro-manganese silicon (Keeney)*

	No. 1, per cent	No. 2, per cent	No. 3, per cent
Silicon.....	24.10	24.60	24.10
Manganese.....	74.20	70.30	55.00
Iron.....	0.77	3.80	19.00
Aluminum.....	.....	0.40	0.40
Calcium.....	.....	0.30	0.30
Magnesium.....	.....	0.20	0.20
Carbon.....	0.30	0.35	0.35
Sulphur.....	0.01	0.02	0.02
Phosphorus.....	0.02	0.04	0.04

Ferro-silicon.—This is the most extensively used of all the alloys produced in the electric furnace. If all ferro-alloys be considered, it is second only to ferro-manganese in the amount consumed. It was first prepared in 1810 by Berzelius, who, with a mixture of iron shavings, silica and carbon, obtained an alloy containing 9% of silicon. In 1811, Strohmayer repeated the experiments of Berzelius, and prepared a series of alloys containing from 2.20 to 9.30% of silicon. Valten made ferro-silicon at Terre-Boire in 1872 by the reduction of iron oxide and silica in a crucible with carbon. He got from 10 to 12% silicon in the product. Using iron turnings, silica, and carbon, he obtained an alloy containing 22% of silicon. From this small beginning arose the ferro-silicon industry of the United States.

Electric ferro-silicon is produced in four grades according to Keeney, which is as follows for each grade: 25 to 30%, 45 to 50%, 75 to 80%, and 90 to 95%. These products are sold on their silicon content, because the carbon content, owing to its usual low percentage, has no effect on the price, as in the case of other alloys. The analyses of four grades of electric ferro-silicon follow:

TABLE 71.—Analyses of electric ferro-silicon

Constituent	Silicon content			
	25 to 30%	45 to 50%	75 to 80%	90 to 95%
Silicon.....	30.50	49.50	78.00	88.50
Iron.....	68.00	49.00	20.00	9.30
Manganese.....	0.35	0.30	0.25	0.15
Aluminum.....	0.10	0.15	0.10	0.15
Magnesium.....	0.10	0.15	0.30	0.30
Carbon.....	0.35	0.30	0.30	0.25
Sulphur.....	0.02	0.015	0.015	0.015
Phosphorus.....	0.04	0.03	0.03	0.03

Ferro-molybdenum.—This alloy, according to Keeney, is generally manufactured in the electric furnace from the raw sulphide ore, molybdenite (MoS_2). It is also made by the

reduction of the roasted sulphide with carbon in a crucible, or an electric furnace. Analyses of ferro-molybdenum follow:

TABLE 72.—*Analyses of ferro-molybdenum*

Constituent	Analysis number			
	1	2	3	4
Molybdenum.....	85.80	75.00	85.20	50.311
Iron.....	10.963	18.50	14.047	48.92
Carbon.....	3.07	4.00	0.45	0.35
Silicon.....	0.11	0.20	0.252	0.30
Aluminum.....	.....	0.10	.....	.....
Calcium.....	.....	0.15	.....	.....
Manganese.....	.....	0.15	.....	.....
Sulphur.....	0.05	0.03	0.031	0.03
Phosphorus.....	0.007	0.03	0.02	0.02

According to "Molybdenum Commercial Steels," published by the Climax Molybdenum Co. of New York, molybdenum is classified in the periodic system of elements as a member of the chrome family, therefore its effect on steel is more or less similar to that of chrome. The addition of molybdenum (as ferro) has been proved to improve the physical qualities of chrome-carbon and other steels, and five types of molybdenum steels for forgings, springs, case-hardened parts, etc., have been developed, as under:

Type	Composition, per cent						
	C	Mn	Cr	Si	V	Mo	Ni
MO (chrome-molybdenum).....	0.15-0.40	0.40-0.80	0.70-1.10	0.10-0.20	....	0.25-0.40	.....
MS (chrome-molybdenum).....	0.40-0.50	0.60-0.90	0.80-1.10	0.10-0.20	....	0.25-0.40	.....
LM (chrome-nickel-molybdenum).....	0.25-0.35	0.50-0.80	0.70-1.00	0.10-0.25	....	0.30-0.50	2.75-3.25
NM (nickel-molybdenum).....	0.20-0.40	0.25-0.50	.....	0.10-0.20	....	0.30-0.70	3.00-5.00
VM (chrome-vanadium-molybdenum).....	0.39	0.48	1.06	.....	0.17	0.85	.....

When ferro-molybdenum is employed in the open-hearth furnace, it may be introduced into the steel (1) kegs and all, just after the charge becomes plastic and a little before the

melt becomes level—that is, before the lime begins to come up; (2) kegs and all just after the final additions of ferro-manganese and ferro-chrome have been made—that is, a few minutes before the furnace is tapped; and (3) when the ferro-molybdenum is added in the ladle, it is advisable to melt it first and then pour it into the molten stream of steel as the furnace is tapped. No. 1 and 2 methods are much simpler than No. 3. If calcium molybdate is used instead of ferro-molybdenum it should be added in the early stages of the heat, not with the charge owing to possible loss in the furnace bottom, but preferably a little before the melt becomes level. When the electric furnace is employed, the calcium molybdate may be added after skimming off the first of phosphorus slag, the final or white slag indicating that reduction has been completed. Ferro-molybdenum may be added as above or any time after the final slag has been formed.

Spiegel, spiegeleisen or mirror iron.—This alloy contains from 10 to 40% of manganese. The silicon limits are sometimes specified, as it is desirable to know how the same will run. A typical analysis follows:

Analysis of spiegeleisen

	Per cent
Manganese.....	20.50
Iron.....	73.61
Silicon.....	0.76
Carbon.....	5.18
Sulphur.....	0.002
Phosphorus.....	0.055

Ferro-tungsten.—This alloy, with a low percentage of tungsten, was made by Berthier in 1834, according to Robert M. Keeney in Bulletin 77 (1914) of the U. S. Bureau of Mines.* Caron studied iron-tungsten alloys in 1868, and determined that the hardness increased with the percentage of tungsten. In 1866, Biermann made some ferro-tungsten from tungstic trioxide and iron in the crucible. This method was used up to the time of the introduction of the electric

* See also Bulletin 187 (1921) on manufacture of ferro-tungsten in Colorado.

furnace in 1900, since when most of the ferro-tungsten has been made in the electric furnace, although small quantities containing less than 60% of tungsten are still manufactured in the crucible. The crucible product is made by the reduction of tungstic trioxide with carbon, the concentrate being mixed with carbon and flux, and heated to a high temperature in a gas-fired furnace. The crucible is clay-lined. In making a 65 to 75% tungsten alloy, the crucible will last only one heat; with a 30% product about 3 heats are obtained. In the electric furnace the tungsten ore is reduced with carbon by the arc, and may be either tapped out, or allowed to solidify and removed by dismantling the furnace. Analyses of ferro-tungsten follow:

TABLE 73.—*Analyses of ferro-tungsten*

Constituents	(1) Per cent	(2) Per cent	(3) Per cent
Tungsten.....	73.00	78.50	83.00
Carbon.....	3.50	1.17	0.60
Iron.....	19.00	18.50	15.50
Silicon.....	0.40	0.30	0.40
Manganese.....	3.50	0.40	0.20
Calcium.....	Trace	0.10	0.151
Arsenic.....	0.40	0.10	0.10
Tin.....	0.10	0.05	0.05
Sulphur.....	0.05	0.04	0.04
Phosphorus.....	0.03	0.015	0.015

Ferro-vanadium.—This alloy is made by the thermit process, by reduction of the oxide (V_2O_5) with carbon in a crucible; or by reduction of vanadate of iron with carbon in a crucible; also by reduction of the oxide, sulphide, or vanadate of iron with carbon in the electric furnace. Vanadium is rather difficult to reduce, and as a result, excess carbon is used which is absorbed up to about 6% by the alloy. Typical analyses of ferro-vanadium are given in table 74.

Ferro-titanium.—This alloy is made by two methods: (1) by reduction of titaniferous ores or concentrates with carbon in an electric furnace; and (2) by reduction by aluminum—the thermit process. When reduced by carbon, the titanium

exists in the alloy as carbide of titanium, hence this alloy is known as "ferro-carbontitanium." When made by the thermit process, the alloy contains aluminum, and is known as "carbon-free ferro-titanium." Analyses of these alloys were given under Titanium.

TABLE 74.—*Analyses of ferro-vanadium*

Constituent	Grade with 50% vanadium	Grade with 25 to 30% vanadium
Vanadium.....	55.00	34.10
Iron.....	40.00	64.10
Carbon.....	4.00	1.42
Silicon.....	0.30	0.12
Aluminum.....	0.10	0.12
Manganese.....	0.30	0.12
Sulphur.....	0.03	0.03
Phosphorus.....	0.04	0.009

Other less used ferro-alloys are: (1) Ferro-aluminum, now fallen into disuse. It contained about 10% of aluminum. (2) S. A. M. alloy containing about 8% silicon, 7% aluminum, over 8% manganese, and 0.075% phosphorus. (3) Ferro-phosphorus contained between 20 and 30% of phosphorus. (4) A ferro-sodium was on the market at one time, and contained around 25% of sodium, and was free from lime and excess carbon.

CRUCIBLE STEEL

The crucible method of melting steel is still practiced, although the electric furnace has largely displaced it. Crucible castings are small, usually under 100 lb. in weight; and on account of the nature of the process are comparatively high in price. As it is not possible to remove impurities in the crucible, the process is dependent upon the selection of raw material of certain composition to get castings of the desired analysis; and as the supply of this kind of raw material is always limited, it is not always possible to meet the requirements specified. One of the earliest crucible steel casting

plants was that of the J. A. & P. E. Dutcher Co., at Milwaukee, Wisconsin. This was one of the first plants to use the Nobel oil-fired furnace for melting steel in crucibles, which on that account later received the name of the Milwaukee furnace. The first type of this furnace, such as used by the Dutcher Company, is shown on figure 88, and it will be noted that it consisted of a rectangular enclosure of firebrick, divided into three chambers by partitions of firebrick, having ports alternately at top and bottom. Underneath this melting chamber was a flue connecting with the chimney. This

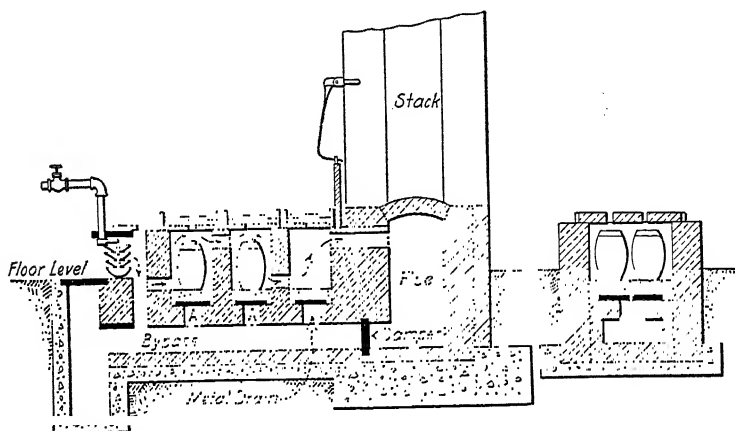


Figure 88.—Original Nobel furnace as used for melting steel, using crucibles.

flue was the by-pass for the flame when the pots were being removed, and during the melting period it was closed by a damper, as shown. The first improvement on this furnace was to omit the bridge walls, the crucibles being stood in three rows of two each in the rectangular box, as on figure 89 in this type the by-pass was retained. Later on this was dispensed with, and the furnace then became a simple rectangular hole in the ground. The furnaces were built in a large rectangular pit, similar to the ashpit of coke-fired brass-melting furnaces. They were placed with their long sides parallel, being bricked up from the floor of the pit, and encased with iron plates to hold them together against the

racking effects of expansion. They stood about a foot above the floor, and a liberal working space was provided between each furnace, and the entire pit was properly covered with gratings, making it a continuation of the foundry floor. The external dimensions of each furnace were: length, 9 feet; width, 5 feet; depth of pit, 5 feet; and height of furnace, 6 feet. The size of the melting chamber was: length, 4.5 feet; width, 3 feet; and depth, 3 feet. Each furnace connected with a flue that ran across the pit at the rear, and which in turn connected with a chimney. There were four furnaces

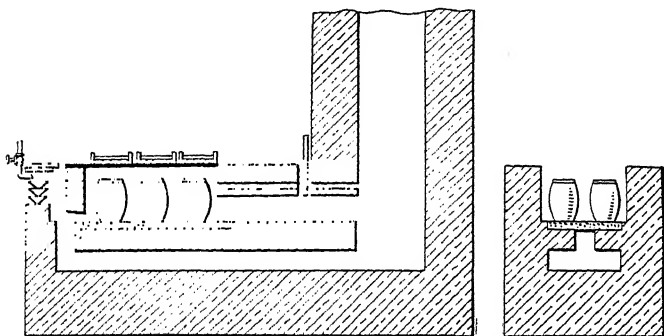


Figure 89.—Simplified Nobel furnace for melting steel in crucibles.

to a pit, one of which was always idle for repairs. The output from each furnace was 3000 lb. of melted steel per day, the output from the battery being 9000 lb. The following is a typical heat of steel:

<i>Crucible steel mixture</i>	
	Per cent
Mild steel boiler punchings.....	79.00
Returned foundry scrap.....	20.00
Ferro-silicon.....	0.60
Ferro-manganese.....	0.30
Aluminum.....	0.10

Powdered charcoal is added to raise the carbon, probably from 60 to 70% being absorbed. From new pots about 0.25% of carbon is absorbed by the steel, and from old pots about 0.15%. What is termed "medicine" is also frequently added; it may consist of potassium ferrocyanide to promote carbon-

ization; and sal-ammoniac, salt, and manganese oxide to thin the slag.

A level teaspoonful is used to a pot of metal. It is necessary to use scrap of known and guaranteed phosphorus content when really excellent steel is wanted. Swedish horse-nail scrap is in demand on account of its purity; and if a low sulphur, low-phosphorus cast iron is at hand, it can be used in the charge to introduce the carbon required. The melting of boiler punchings and Swedish iron in a coke-fired furnace to make steel in crucibles is a tedious and laborious occupation. In the early history of the crucible steel industry of the United States, coke-holes were used; and as they are still in use in brass foundries, and sometimes refractory metals or alloys may have to be melted in them, it will be advisable to outline the method as described by the author of this volume in *The Iron Age*, of August 19, 1897:

Melting steel in a brass furnace.—There were no especial peculiarities about the furnace that was used; it was an ordinary furnace consisting of a boiler-iron shell lined with firebrick and connected with a 40-ft. stack. The first experiments were with high-carbon steel, and it was thought that this could be used, and that by annealing, the castings could be so softened that they could be machined, but a few experiments showed this could not be done. If soft castings were desired, a low-carbon steel must be melted. A brass-melting furnace was being used, and the hard steel experiments served one useful purpose, namely, that this type of furnace was too shallow for high temperature work. The original depth of the furnace was 27 inches, and diameter, 26 inches; it was deepened to 36 inches. The material melted was horse-nail clippings (Swedish iron) and boiler punchings. In charging the furnace, the crucibles were stood on a base 9 inches high. This base at first consisted of three pieces of firebrick, placed one upon the other, and they were put in position on the grate-bars before lighting the furnace. After the fire was started, the coke was allowed to burn down until there was a solid bed of fire, level with the top of the base. This was first cleaned of all particles of coke, then the crucible was stood thereon and was coked up around the sides to the top, and the fire was allowed to burn until a cherry red heat was attained, when the coke was poked down to fill any vacant spaces around the pot, and then the latter was buried in coke up to the top of the furnace. The crucibles were covered with the bottoms of worn-out pots, chopped off below the bilge. A hole two inches in diameter was

made in this cover which was covered with a piece of firebrick while the melting was in progress.

After the crucible had been buried in coke (a depth of 4 or 5 inches being over the top) the furnace cover was rolled over and sealed around the edges with molding sand, and the furnace was left for 45 minutes. At the end of this period the coke on top of the crucible was heated to a bright red, while around the sides it had attained a white heat. The red-hot coke on top of the crucible was now poked down to fill the vacancies around the sides where the coke had burned away, fresh coke being thrown on top again, and the furnace was re-sealed and left for another 45 minutes. This operation was repeated at the proper intervals for five hours, at the end of which time the metal was sufficiently hot to be removed and poured.

The most important part of the process is the poking down, as a little laziness on the part of the melter will make all the difference between success and failure. No half measures will do; it is not enough to stand 2 or 3 feet away and jab at the coke, the bar must be held vertically and driven through the fire all around the crucible, hitting the grate-bars at every stroke. (A heavy bar is necessary.) In this manner hot fuel is always kept around the base and bottom of the crucible. Unless this is done, the fire will die out to a height of about 8 inches above the grate, the bottom of the crucible will chill, and the metal will be melted on top, and remain solid on the bottom.

Another cause of failure is in the condition of the furnace. As may be expected, the intense heat rapidly cuts away the lining. When this has become ragged, slag-covered, and barrel-shaped, it is impossible to take out a heat, as the furnace will "scaffold"—that is, a solid clinker will form from the walls of the furnace to the top of the base. This clinker is so tenacious while hot that it is a difficult matter to break through it even with a heavy bar and sledge, and even should it be broken after much exhausting labor, it will form again before the metal has a chance to melt. The writer has seen furnaces in this condition, devouring coke for six or seven hours, producing on the top an intense heat, and yet the contents of the crucible would be as solid at the end of this time as when first put in. The only remedy is a new lining. To do good work the furnace must be kept in good order, when, if intelligently managed, it will produce the desired results. Another trouble is caused by the base. The common firebrick, even of the best grade, melts, and lets the pot fall over, and as it is softened by the heat it is crushed by its own weight as it leans sidewise against the furnace wall. The next brick tried was taken from the worn-out lining of a blast-furnace, and while it withstood the heat better than the other brick, it caused annoyance by sticking to the bottom of the crucible, making it both difficult and dangerous to pull out the pot. Bottoms were then made of old crucibles, cut off to a suit-

able height, and these created more trouble than anything tried, as they became so firmly cemented to the crucible that it was almost impossible to detach them, and unless detached it was equally impossible to get the pot out of the furnace while the metal was sufficiently hot to pour, as the time is very limited. This difficulty of getting out the crucible with base attached was caused by the bottoms being wider at the grate-bars than where attached to the bottom of the crucible, owing to the shape of the cut-off crucible from which the base was made—the old pots being cut off at the bilge and set on the bars bottom upwards—consequently the coke wedged itself between the base and the sides of the furnace and being glued by the melted slag made practically one solid mass. To prevent fusion of base to crucible, silica sand, charcoal, and about everything else that could be thought of was tried as a parting, but without avail. As the base was the cause of so much trouble, efforts were made to dispense with it. A bed of coke was placed in the furnace of such a depth that when the crucible was placed thereon, its top was level with the mouth of the furnace. Coke was placed around the sides, and as the pot sank into the fire, more coke was placed on top, as in the manner before described. The trial was a failure, however, as the coke under the crucible burned away so rapidly, the latter reached the grate-bars before the contents were anywhere near the melting point. The pot was then lifted out, and another bed of coke placed on the grate-bars, and the crucible was then replaced and re-coked. Of course, the crucible and contents were chilled by the cold coke, but still retained a considerable amount of heat, and it was on this hopes were built, but all in vain, the result was as before. Anthracite coal was then tried in a similar manner, but with exactly the same results. As a result of these experiments, which were continued for a considerable time, it was found that the important thing was to keep heat around the base and bottom of the crucible, which would keep the slag liquid between the crucible bottom and base. If allowed to freeze it would act as a strong cement. When fluid it offered no resistance to the lifting of the pot, and to get these desirable results, the furnace had to be in good condition at all times. It must be re-lined frequently, and the poking down of the coke had to be done thoroughly. The best way was to have plenty of help, changing men as they grew hot and tired with their exertions and the intense heat of the furnace. In poking down, the furnace cover must be used as a shield, being removed only enough to allow the poking to be done, and shifted as the work progresses around the crucible.

Oil furnaces.—The oil-fired furnaces shown on figures 88 and 89, were a great improvement over the solid-fuel furnaces. For a long time they were constructed as in figure 88, with bridge-walls dividing the melting chamber into three compartments, and with a by-pass flue underneath into which the flame could be deflected by a damper when crucibles were to be removed from the melting hole.

In this type of furnace, only four crucibles could be worked, those in the second hole were insufficiently heated to melt their contents; they were simply heated to conserve fuel. The first chamber was the melting chamber, and when these pots were withdrawn, the pots in the second hole were moved forward, and two cold pots placed in the second hole. When a pot broke, the metal was supposed to drain through the openings *A A* into the by-pass from which it could be recovered. This opening was covered with a piece of broken crucible, and when a pot gave way the melter was supposed to know it and to punch away this piece of crucible, thus opening the hole to the by-pass. The bottoms of the melting holes were made of ground coke as shown by the dotted lines. As a matter of fact, the melter seldom knew when a pot broke, owing to the intense heat of the compartment, and the pots would spring leaks near the bottoms. The result was that the steel congealed in the melting chamber, from which it was often impossible to remove it, without pulling down the bridge-walls.

The life of the bridge-walls was very short, as the fast moving and intensely hot flame cut them away rapidly. The result was the furnace had to be repaired each week, and owing to the great expense of refractories and labor, the coke-hole was frequently used in place of the oil-fired furnaces.

In time, however, the furnace was simplified, the first step being to eliminate the bridge-walls as shown on figure 89. This was a great economy, but the by-pass was still retained. Finally, the by-pass was also eliminated, because it was found that if the oil supply was shut off, the residue in the pans soon burned out and the flame vanished, and the furnace could be opened just the same as when the by-pass was used. This saved considerable brickwork, and was a further economy. It will be noted that six pots are placed in the furnace having no bridge-walls; later six and eight pots were placed in at one time.

STEEL CASTINGS

Converter steel castings.—This method of making steel was the invention of the late Sir Henry Bessemer. The method used in modern steel foundries is an adaptation of the Bessemer process to fill the requirements of steel casting practice. The raw material is cast iron, which is first melted in a cupola, then transferred while molten to a heated converting vessel or converter. Here the cast iron is changed to steel by the simple expedient of burning out the carbon, by supplying oxygen in the form of air, for supporting combustion. The air blast, usually at a pressure of 4 lb. per sq. in., enters

the converter at the side, instead of bubbling up through the metal as in the original manner. The burning of the metal-loids in the cast iron produces intense heat, therefore, a distinguishing feature of the Bessemer converter method is the fluidity of the metal, which renders it possible to run very



Figure 90.—Converting (bessemerizing) iron into steel (courtesy U. S. Bureau of Mines).

thin castings. In the Pittsburgh district the blow continues for about 11 minutes, the operation being shown on figure 90.

Open-hearth process.—This is the most economical process of making heavy steel castings. Pig iron and scrap steel is melted and then oxidized by means of iron ore, removing the carbon, silicon, and manganese in the metal, and then restoring them to a definite analysis by additions of suitable ma-

terials. The usual sizes of furnaces are from 15 to 20 tons. In some cases no refining is attempted. Thus, the open-hearth furnaces of the Birdsboro Steel Foundry & Machine Co., are oil-fired and consist of a hearth 18 feet long, and 10 feet wide; walled in, roofed over, and held together by cast-steel buckstays. The oil is delivered to burners at 40-lb. pressure, and is atomized with compressed air at 60-lb. pressure. Air valves are reversed every 15 minutes. The furnace is acid-lined, and a typical charge for turbine casings follows:

Charge for turbine casings

	Pounds
Low phosphorus pig iron.....	5,000
Boiler-plate clippings.....	15,000
Old couplers.....	6,390
Old forgings.....	9,810
Ferro-manganese.....	280
Ferro-silicon.....	195
Sand.....	100

The heat is charged in about $3\frac{3}{4}$ hours, and tapped from $5\frac{3}{4}$ to 7 hours. The analysis from the above charge will be about:

	Per cent
Carbon.....	0.30
Manganese.....	0.45
Silicon.....	0.20
Sulphur.....	0.033
Phosphorus.....	0.028

When properly treated, the physical properties will approximate the following:

Tensile strength, lb. per sq. in.....	70,000
Elastic limit, lb. per sq. in.....	39,000
Elongation, % in 2 inches.....	15
Reduction of area, %.....	20

The furnace will consume from 42 to 45 gallons of oil per ton of metal charged. The roofs last approximately 800 heats.

Figure 91 illustrates a small open-hearth furnace known as the McLain-Carter furnace, used for melting steel for casting purposes. A considerable quantity of steel is now

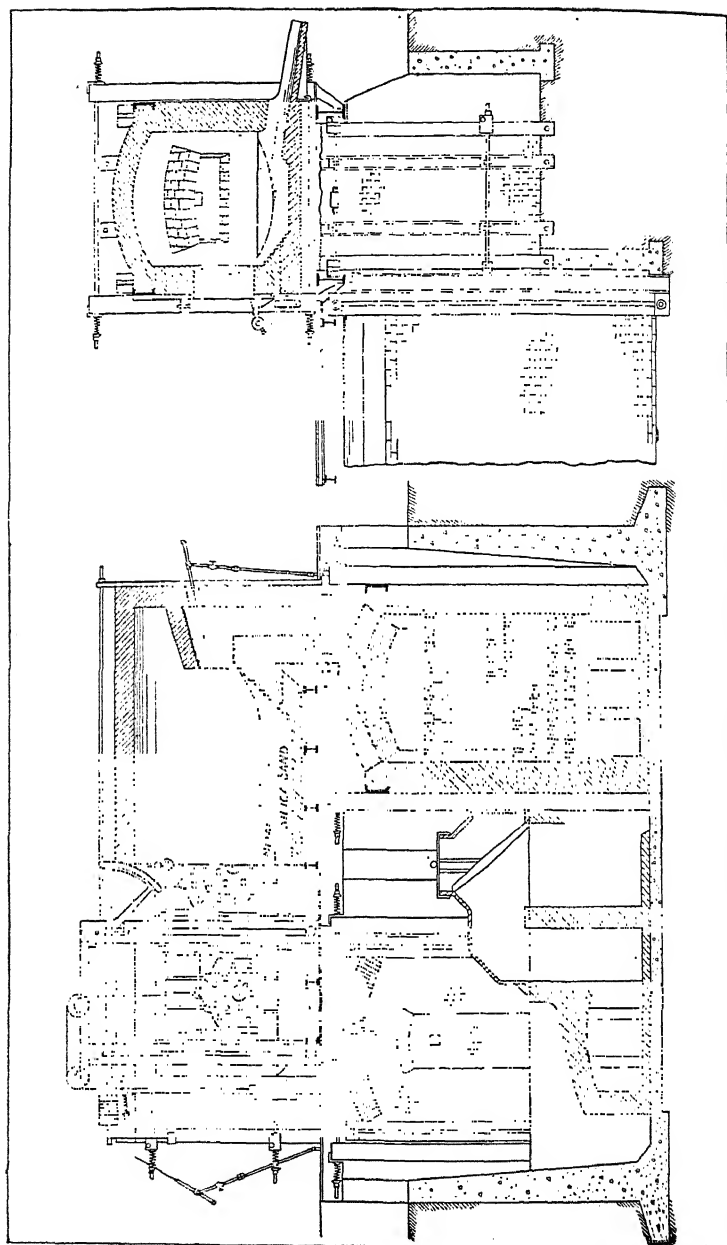


Figure 91.—General arrangement of small open-hearth furnace (McLain-Carter).

melted in the electric furnace. Figure 92 shows a section of a 6-ton steel-melting electric furnace, with part cut away to show the bottom make-up, which consists of a layer of magnesite brick, on which is the bottom of rammed magnesite and on that the charge of steel scrap to be melted.

OTHER STEELS

Manganese steel.—For special purposes iron is sometimes alloyed with up to 14% of manganese in order to produce manganese steel, which is distinguished by great hardness.

Ferro-manganese, with up to 85% of manganese, is intentionally produced to be used as addition in iron works, especially in the manufacture of mild steel.

The ferro-manganese is usually added to the molten steel after it is tapped into the ladle. For ordinary steels, the ferro-manganese is used for the removal of oxygen from the metal, so that a considerable proportion of the manganese finds its way into the slag, leaving only 0.5 to 1% of manganese in the finished steel. This quantity seems to have almost no influence on the physical properties of the steel except to counteract the tendency to red-shortness; but as the percentage of manganese approaches 3% an excessive brittleness shows itself, rendering the metal almost useless; and when 5 to 6% is reached the steel is so hard and brittle that it can readily be powdered by crushing. However, when 7% is exceeded, an extraordinary change takes place immediately, and with from 8 to 20% an alloy known as "Hadfield's manganese steel" is obtained, which possesses remarkable characteristics. An excellent quality of razors and axes have been made from Hadfield steel containing 13.75% manganese and 0.85% of carbon. This alloy, after forging and water-toughening gave, on testing, a tensile strength of 65 tons per square inch, and almost 51% elongation.

Manganese steel is difficult to machine and file, but it can be partly softened by treatment in the following manner:

The tool is heated to slightly over 1832°F. , and suddenly quenched in cold water nearly at the freezing point, when the metal becomes soft enough to be easily filed or even planed. To restore the former hardness, heating to a bright red heat (say 1382°F.) and slowly cooling in the air is sufficient.

One of the developments of the World War was the utilization of manganese steel for helmets and armor. For the former, a steel of the following analysis was satisfactory according to John A. Coyle: Carbon, 0.37 to 0.47%; manganese, 0.95 to 1.05%; nickel, 2.00%; vanadium, 0.15 to 0.25%; silicon, 0.15 to 0.25%; phosphorus, 0.02% (maximum); and sulphur, 0.02% (maximum). This material worked very readily, the product after annealing being a dead-soft sheet which could be bent flat upon itself in any direction without sign of fracture. The final annealing was done in pots at 1700°F. , for 10 hours, cooling in the furnace requiring 14 hours to drop to 60°F. After being annealed as described, the helmets were oil-quenched from 1500°F. , and drawn in oil at 450°F. By the use of this alloy, 106,000 helmets were made without a single rejection. They were subjected to a ballistic test as follows: A sheet 0.035 inch thick (20 gage) should withstand a 0.44 caliber Colt bullet with a muzzle velocity of 840 feet per second, at a distance of 10 feet, fired point blank—this was successfully met.

The armor required by the U. S. Army must resist penetration by a copper covered bullet from a Springfield rifle with a muzzle velocity of 2140 feet per second, and at a range of 50 yards. The thickness of the sheet was specified at 0.175 inch. This was met by the same steel as used for the helmets, but a variation in nickel was allowed from 1.85 to 2.15%.

The principal use of manganese steel is for purposes where extreme hardness is necessary, such as the jaws and liners of rock-crushers, liners for grinding machinery, lips and teeth of dredge buckets and steam-shovel dippers, car wheels, and railroad crossings and switches.

Chrome steel.—According to the investigations of Berth-

ier, Frémy, Smith, and others, iron and chromium unite in all proportions. Chrome steel is easily made by adding ferro-chrome to nearly finished steel in the furnace. Ferro-chrome with about 40% of chromium is employed, and allowance is made for about 20% loss in the slag, which must be basic. For high-class tool-steels it is preferable to use a refined ferro-chrome alloy containing from 60 to 75% of chromium, made by reducing chromic iron ore in crucibles.

The effect of chromium in steel is, in general, to raise the tensile strength as the percentage of chromium increases, without seriously diminishing the ductility. Up to 1% of chromium has little or no effect, either on the tensile strength or hardness of the steel even on quenching. In the absence of carbon, as much as 4% of chromium produces no greater hardening than the same quantity of aluminum, but with about 1% of carbon and from 2 to 3% of chromium, great stiffness with undiminished toughness is attained. Such material is suitable for armor-piercing projectiles, if suitably hardened and tempered to give the formation of the intensely hard carbides of iron and chromium, suitable for penetration of armor-plates.

Low-carbon chrome steels can be forged well with up to about 12% of chromium present, but, as the carbon increases, forging makes the steel hard and brittle. This brittleness can, however, be easily removed by annealing, and the steel is rendered excessively hard by quenching in water.

In addition to shells, chrome steel with about 1.2% of chromium is very suitable for making files. Other uses of this alloy are the manufacture of locomotive springs, tires and axles, shoes and dies for stamp-mills, and any tools requiring great hardness. Armor-plate is frequently made with a combined chrome-nickel steel; so are a certain brand of shovels. For safes, alternate layers of chrome steel and wrought iron are welded together and cooled suddenly. The hardness of the quenched chromium steel resists the burglar's drill, while the ductility of the wrought iron resists the blows of his hammer.

Under the microscope, the effect of chromium on steel is

seen to be an interference with the growth of the iron crystals, the granular structure being very minute; and this, no doubt, accounts for the modifications which the chromium effects on the mechanical properties of steels. The effect is not proportional to the chromium content, small amounts being more active than larger amounts. At first, the chromium seems to dissolve in the steel, but as the amount increases, a double carbide of iron and chromium is formed, which possesses great hardness. This occurs in the steel either as isolated globules, or it may be dissolved in the metallic matrix (on annealing at 2192° F.), bestowing a very high degree of hardness on the alloy.

Tungsten steel.—Although tungsten by itself melts only with great difficulty, it readily unites with iron, forming an alloy known as ferro-tungsten. Such an alloy containing about 80% of tungsten is, for the preparation of tungsten steel, added to the steel while in the ladle. It is, however, preferable to use crucibles for melting the alloy for special high-grade tool-steel. Tungsten steel does not make sound castings except with the addition of a small quantity of aluminum and silicon. The fluidity of the alloy is slightly less than that of ordinary steel. The general effect of tungsten in steel is to make it intensely hard and brittle. It is very difficult to forge, and it cannot be welded when the tungsten content exceeds 2%. One peculiarity of tungsten steel is that in the absence of carbon its strength or hardness is not increased by tempering. With a higher tungsten content, the steel can be worked only with the greatest difficulty. The higher grades cannot be worked with the file, and as none of them can be tempered, they must be shaped at one forging, and then ground to the form desired. Tungsten steel may be cast in the form of tools which can be ground to a fine edge. Like chrome steel, tungsten steel can be readily worked at a red heat, but has to be handled with the greatest care to obtain the best results. An addition of tungsten gives to steel a very fine and uniformly crystalline structure, and such steel is less affected by the atmosphere than ordinary

steel. Tungsten steel may also be prepared by adding metallic tungsten to molten steel in a crucible.

Bending tests conducted on bars of tungsten steel show that, as cast, the increase of the percentage of tungsten gradually diminishes the toughness, especially after 3.5% is reached, this point being comparable with 1½% of tungsten if the bars are annealed at about 1652° F., and then water-quenched, when a distinct hardening is noticeable. Unlike either manganese or nickel steels, which, although brittle during the range from 3 to 7% for manganese and from 10 to 15% for nickel, become tough with higher percentages, tungsten steel does not show this peculiar return to toughness, since the angle through which the bars bend decreases with the increase of tungsten.

On fracture, tungsten steels show very marked peculiarity. First, a very fine crystalline structure commences with 1.5% of tungsten, and up to 7% the grain is extremely close, but not silky. This characteristic appearance of silkiness only appears when the carbon content exceeds 1¼% and is apparently due to the presence of a carbide of tungsten in association with the carbide of iron.

Tungsten steels of high-carbon content are very retentive of magnetism, and an alloy with 5% tungsten, with 0.62% carbon and 0.55% manganese, is found very suitable for the manufacture of permanent magnets in electric meters. The highest magnetic power attainable with the greatest retentiveness is reached when the tungsten content is between 4 and 7%. Low-carbon steels with tungsten do not show this magnetic retentiveness.

The special use of tungsten is for the production of self-hardening steels—that is, those which can be made hard enough to retain a cutting edge by heat treatment alone, without water-quenching. Such steels, if plunged when red hot into water, simply crack or split. They usually contain from 5 to 8% of tungsten, with 1.5 to 2.5% of carbon. The following are some typical analyses of special tungsten steels: *

* Greenwood: Steel and Iron.

Analyses of tungsten steels

	Carbon, %	Tungsten, %	Manganese, %	Silicon, %	Chromium, %
Mushet (Osborn)...	1.65	5.8	2.12	1.36	0.45
Allevard.....	0.42	6.22	0.29	0.5	
Mushet (ordinary)...	2.0	7.81	0.19	0.9	
Mushet (special)...	2.3	8.22	1.72	1.60	

The first mentioned steel is peculiar in that it can be successfully softened for machining by heating to the temperature of incipient redness (about 932° F.) and quenching in water.

The second, of French manufacture, by quenching in water at 1112° F., can be rendered very hard, or of only medium hardness; or quite soft, according as the temperature of the preliminary heating is raised to 2372°, 1832°, or 1562° F., respectively.

The Taylor and White special "quick speed" cutting steels with 5% of tungsten, 4% of molybdenum, and 4% of chromium can be worked at a red heat without losing their cutting edge. The temper of tools made from this alloy cannot readily be destroyed even when the rate of cutting makes the working face of the tool approach a low red heat.

Vanadium steel.—The element vanadium was discovered about a century ago in a lead ore from Zimapan, Mexico, by the Mexican mineralogist Del Rio, who, by reason of its forming red salts, christened it *erythronium*. This discovery, however, was later on discredited, Collet-Descotils declaring erythronium to be impure chromium, and the mineral from which it was obtained, a lead chromate. Wöhler, however, later on proved the mineral to be lead vanadate. In 1830, the element was re-discovered by Sefström, in bar iron from Eckersholm, Sweden, and was called vanadium by him in deference to the Scandinavian deity Vanadis (a by-name of the goddess Freia). The element was isolated, about thirty years later, by Sir Henry Roscoe.

The steel is particularly suitable for crank-shafts, cranks, propeller shafts, locomotive and wagon axles, journals, loco-

motive frames and automobile chassis, etc. The following are results of experiments which clearly show the influence of vanadium on chromium:

TABLE 75.—*Influence of vanadium on chromium steel*

Alloy	Tensile strength, lb. per sq. in.	Elastic limit, lb. per sq. in.	Reduction of area, %	Elongation, %
Manganese carbon steel.....	56,000	33,000	60	35
“ “ “ plus 0.5 % chromium...	71,000	46,000	61	33
“ “ “ “ 1% “	80,000	51,000	57	30
“ “ “ “ 0.10% vanadium...	71,000	60,000	60	31
“ “ “ “ 0.15% “	75,000	64,000	59	26
“ “ “ “ 0.25% “	81,000	71,000	59	24
“ “ “ “ 1% chromium and 0.15% vanadium.	101,000	75,000	57	24
“ “ “ “ 1% chromium and 0.25% vanadium.	128,000	104,000	46	19
“ “ “ “ 1% chromium and 0.25% vanadium tempered.....	178,000	148,000	48	16
“ “ “ “ 1% chromium and 0.25% vanadium tempered.....	203,000	188,000	45	12

The greatest part of the vanadium produced has come from the large and unique deposit of vanadium ore near the summit of the Andes at Minasragra, in the vicinity of Cerro de Pasco, Peru, and is owned by the Vanadium Corporation of America. This rich deposit is made up of the black mineral patronite, which resembles a hard, black clay, or an inferior bituminous coal. It occurs in a shale formation. In fact, the deposit has several times been mistaken for coal, and worked, only to be abandoned because of high sulphur. Patronite contains about 20% vanadium, and about 60% sulphur.

After the ore is mined, it is roasted to reduce the sulphur content, after which it is sacked—about 110 lb. each—and transported to Callao, Peru, for shipment to the reduction works at Bridgeville, Pennsylvania. Other deposits of vanadium ore are the roscolite deposits of Colorado, which, however, contain but a low percentage of the element. Oxide of vanadium is also obtained as a by-product in the production of radium from carnotite ores in Colorado. Both of these ores occur in sandstone at high altitudes and in arid country.

Vanadium is used as a purifying agent in making steel for a great variety of purposes. Thus it is used in steel for

motor-trucks, gunshields and helmets, machine-gun barrels and their mechanism, gun-mounts and forgings, submarine and destroyer engine crank-shafts and other parts, and also in parts of aircraft and other engines, in engines for automobiles, safe-deposit vaults, metal-cutting saws, and many other steels.

Vanadium steels may be grouped in three classes, namely, (1) those containing vanadium alone; (2) those with vanadium and nickel; and (3) vanadium and chromium. The following are some interesting results obtained by adding vanadium:

Effect of adding vanadium to steel

	Tensile strength, lb. per sq. in.	Limit of elasticity, lb. per sq. in.
Mild steel, low percentage of phosphorus. . .	60,000	35,000
Mild steel, carbonized with cast iron in graphite crucible.	62,000	47,000
Mild steel, with 0.5% of vanadium.	94,000	74,000
Mild steel, with 1% of vanadium, not annealed.	138,000	112,000
Mild steel, with 1% of vanadium, not annealed.	102,000	82,000

This 1% vanadium steel is usually employed for objects subjected to vibration, as it resists the effects of traction admirably.

The second class of vanadium steels is that containing vanadium and nickel. The proportion is usually 0.2 and 0.4% vanadium and 2 to 6% nickel. With these steels a tensile strength of 78,000 to 87,000 lb. per sq. in. is obtained; elasticity of 55,000 to 70,000 lb. per sq. in., and elongation varying from 30 to 35%. After tempering, the resistance to tension and limit of elasticity attain 220,000 and 195,000 lb., and elongation falls from 10 to 8%. Nickel has a peculiar action, as it makes steel hard until 8%, and from 8 to 15% so brittle that one can break it with a hammer, and from 15 to 25% extensibility rapidly augments to become almost stationary. Vanadium makes nickel steel more homogeneous, decreases the fragility which nickel tends to give steel, though

it is rarely employed with more than 8% of nickel. Such steel, from the fact that nickel gives a very great resistance to impact, is specially suited for piston-rods, connecting rods, small shafting, etc.

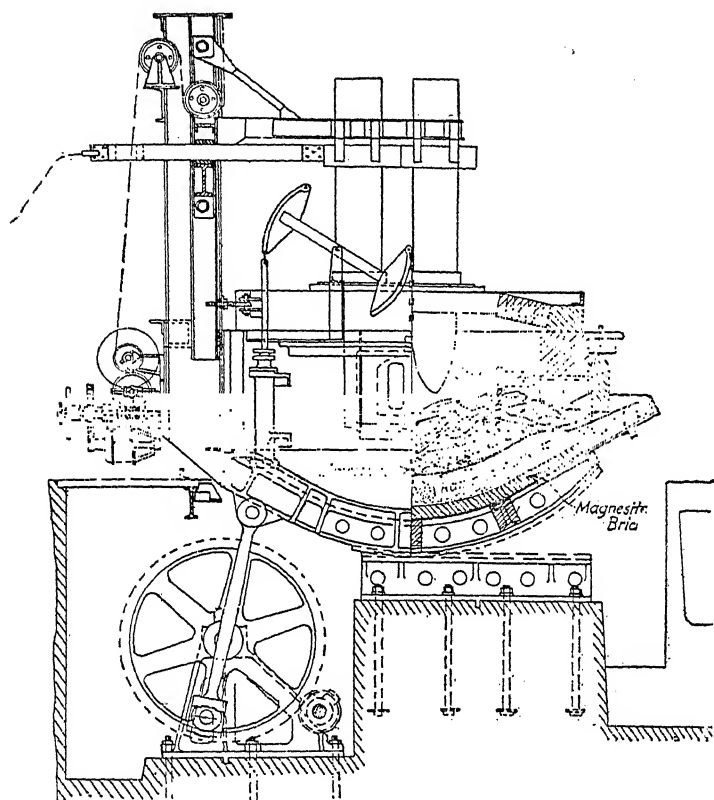


Figure 92.—Section of 6-ton electric furnace showing bottom make-up.

Vanadium-chrome steels.—In the third class of vanadium steels are vanadium-chrome steels, the two best proportions for which are 0.2 or 0.4% carbon, 1% chromium, and 0.2% vanadium.

Chromium augments the resistance to impact and tension, but has a tendency to produce a very hard metal, difficult to work hot, and welding can only be operated successfully by

electricity, owing to the tendency of chromium to oxidize and form slag. Chromium gives a steel difficult to cut and work cold, and the Carnegie Steel Co. could find nothing better to cut this steel plate than a disc revolving at a high rate of speed. This disc, 6 ft. in diameter, mounted like a circular saw, cuts plates 6 inches thick; a jet of steam plays continually on the part being cut. Vanadium in the proportion of 0.15 to 0.25% counterbalances the tendency of chromium and facilitates cutting.

OTHER IRON ALLOYS

Steels of all kinds, as well as malleable iron and cast iron, are alloys of iron, and there are so many and varied that they cover a field alone requiring a lifetime to study. A few examples will be given to round out the chapter on iron alloys. Some of the alloys of iron are very complex as the following representative analyses of high-speed steel and chrome-nickel steel will illustrate:

<i>High-speed steel</i>		<i>Chrome-nickel steel</i>	
	Per cent		Per cent
Carbon.....	0.510		0.300
Manganese.....	0.256		0.600
Silicon.....	0.144		0.100
Phosphorus.....	0.018		0.014
Sulphur.....	0.044		0.010
Chromium.....	7.080		1.680
Tungsten.....	22.680		None
Molybdenum.....	0.479		"
Nickel.....	None		4.360
Iron.....	68.789		92.936

Other examples are:

<i>Invar—a nickel steel</i>		<i>Carbon steel</i>	
	Per cent		Per cent
Carbon.....	0.280		0.750
Manganese.....	0.500		0.200
Silicon.....	0.020		0.020
Phosphorus.....	0.040		0.015
Sulphur.....	0.010		0.015
Nickel.....	33.000		None
Iron.....	66.150		99.000

Carbon steel.—This steel owes its superiority to wrought iron, for many purposes solely to its carbon content, influenced somewhat by the manganese. The other steels have additions of other elements not found in the ordinary iron ores. Sulphur and phosphorus, as before remarked, are natural impurities; the steel might be better without them, but it is almost impossible to eliminate them entirely.

CHAPTER XXIV

MAGNESIUM ALLOYS AND ZINC ALLOYS

MAGNESIUM ALLOYS

ALLOYS having magnesium as a base are easily made and are the lightest alloys commercially used, and are also the most recent additions to the number of metals used in foundries. Success in melting such alloys depends upon watchfulness, for, unlike all other alloys, if left in the furnace a moment too long they will take fire and burn with great intensity, and when burning are very difficult to stop. It is necessary when melting magnesium to stay right at the particular furnace where the work is being done, and the important point is to remove the crucible from the fire at the moment the metal loses its shape and sinks to a molten mass. The heat stored in the crucible walls will be ample to bring the alloy to pouring temperature.

If the above precautions are observed there will be no difficulty in melting alloys of magnesium, and after they are melted they can be cast into molds of sand, provided the molds have been dried before being cast.

If the crucible is left in the fire after the metal is melted, the contents will become overheated and will burn with all the fuss that a magnesium flashlight makes when it is fired. The only thing that can be done is to smother the metal, and in some cases where foundrymen have had the experience of such alloys taking fire, the smothering has been done with sand, borax, or something similar, but totally unsuited for the purpose. Sand is heavier than magnesium, and it will sink to the bottom instead of floating on top where it is wanted for the purpose of smothering the fire, the result being that the magnesium and sand partly react and the magnesium is lost entirely. While there is no particular danger about its

taking fire, it means a considerable financial loss, and for that reason is to be avoided, which can be done by being careful.

Dow metal.—An example of a magnesium alloy is Dow metal, made by the Dow Chemical Co. of Midland, Michigan. An article by E. J. Jenkins in *The Iron Age* gave the properties of this alloy as follows:

Properties of Dow metal

Specific gravity.....	1.79
Tensile strength, lb. per sq. in.....	22,000 to 25,000
Yield point, lb. per sq. in.....	12,000 to 14,000
Compressive strength, lb. per sq. in.....	45,000
Elongation in 2 inches, %.....	3.5
Reduction in area, %.....	3.5
Modulus of elasticity.....	9,000,000
Brinell hardness.....	55 to 75
Heat conductivity as compared with 1000 for pure copper and 0.108 for cast iron.....	0.295
Coefficient of linear expansion from 0 to 800° F.....	0.000028

When this alloy is rolled, drawn, drop-forged, or heat-treated, the tensile strength is increased at each operation, as in the case of all other metals and alloys. With heat-treating, sand-made castings are increased from 22,000 to 25,000 lb. tensile strength up to 30,000 lb. or more, without causing any appreciable change in the yield point; while the elongation and reduction in area are increased to 6%. When drop-forged, the tensile strength is increased to 50,000 lb., and the Brinell hardness rises to 70 or better. These improvements of strength in the case of worked metal is what would be expected, as all worked metal is improved by such work. The main use found for the alloy has been in the manufacture of pistons and connecting rods for automobile, airplane, and motor-boat engines. It is the lightest material that can be used for such a purpose. The claim is made that this alloy differs from aluminum in that there is no permanent growth or set at the working temperature of a piston of an internal-combustion engine. A comparison of the three main piston materials as to weight is as follows:

Metal	Oz. per cu. in.
Dow metal.....	1.04
Lynite (aluminum alloy).....	1.56
Cast iron.....	4.16

Electron alloys.—Magnesium alloys have been known in Europe as “electron” alloys, the composition of which was given by S. Beckinsale in a paper read before the British Institute of Metals, Sept. 22, 1921, as follows:

Composition of electron alloys

Constituent	Alloy A, per cent	Alloy B, per cent	Alloy C, per cent
Copper.....	0.20	0.42	0.62
Zinc.....	4.62	4.24	4.37
Lead, iron, aluminum.....	Traces	Traces	Traces
Manganese and tin.....	None	None	None
Magnesium (by difference).....	95.18	95.34	95.01

These alloys are simply composed of magnesium, zinc, and copper, in the proportions of 95.0%, 4.5%, and 0.5%, respectively. The alloy is made by melting the magnesium with a hardener which carries the zinc and copper into the alloys. The hardener consists of 90.00% zinc and 5.00% copper, which is first made and ingoted. A new graphite crucible, painted inside with alundum cement, is annealed and brought to a cherry red. Next, 5% of the hardener is placed in the bottom of the crucible and melted, but is not allowed to get hot; then the magnesium is fed into the hardener, with the gas adjusted to just keep the crucible hot. A few pieces of magnesium are reserved for cooling, and as soon as all is melted—except these few pieces—the crucible should be removed from the furnace, and the heat within the crucible walls will bring up the temperature to the proper point for pouring. If the metal gets a little too hot and a slight flaring of magnesium starts around the sides of the crucible, a little cooling magnesium may be added.

Make the molds of dry sand facing; bake them, and have them warm when the magnesium is poured therein. The pouring heads and feeders, if the latter are used, should be built up three times higher than for brass; and it will not be harmful if they are even higher than that, as the metal is very light and a higher head is required to get pressure on the mold.

Some of the properties of these three alloys are as follows:

Properties of electron alloys

	A	B	C
Brinell hardness:			
Exterior surface.....	51	51	63
Transverse section.....	50	48	59
Specific gravity.....	1.78	1.79	1.79
Tensile strength:			
Ultimate strength.....	36,064	40,360	41,216
Yield point.....	26,880	17,024	26,880
Elongation in 2 inches.....	10.1	18.0	18.4

The diameter of test piece for tensile tests was 0.180 inch. Elongation measured on 0.64 inch (equals $4\sqrt{\text{area}}$). Compression tests on cylinders, 0.310 inch diameter, and 0.310 inch long:

Yield point, lb. per sq. in. (compression 0.5% with load on). Alloy A = 6720; alloy B = 13,440; alloy C = 18,816.

Permanent reduction in length, at	A	B	C
Load of 22,400 lb. per sq. in., %..	3.9	2.0	1.0
Load of 44,800 lb. per sq. in., %..	10.1	9.1	7.0
Crushing load (fracture occurred by shearing), lb. per sq. in.....	51,520	49,942	53,536

All samples showed equiaxial polyhedral crystals of a single solution. One end of sample C, which had been heated, showed distortion of the grains; these were elongated in the direction at right angles to the axis of the rod. The specimens were polished on fine emery paper impregnated with paraffin wax followed by selvyt, to which a little metal polish had been applied. The specimen to which the trace of polish adhered was then transformed to clean selvyt. A satisfactory etching agent was a solution of 1% hydrochloric acid and 0.5% nitric acid in alcohol. The machining properties of the alloys are very satisfactory, and a good finish is produced by turning. Owing to danger from fire, the manufacturers issue very strict regulations to prevent the accumulation of turnings beyond a

certain quantity in the machine-shops where the alloys are finished.

Magnesium-aluminum alloys.—Magnesium is also alloyed with aluminum. A patent issued to C. B. Backer covers an alloy containing magnesium, over 85% aluminum, over 1.50%; and zinc, over 0.75%. A hard magnesium alloy contains magnesium, 92.00%; copper, 4.00%; and aluminum, 4.00%. It is made by melting magnesium with the 50–50 aluminum hardener, using 8% of the latter, but for the majority of purposes for which these light alloys are used, the amount of hardener will have to be reduced considerably.

Magnesium-zinc alloys.—Magnesium is also simply alloyed with zinc, one alloy consisting of 97.00% magnesium, and 3.00% of zinc. Magnesium has also been alloyed with calcium, which produces a very close-grained silvery-white metal of considerable hardness. The metal superficially air-oxidizes to a dirty gray color, but the coating of oxide is very thin. Such alloys, however, require very careful handling when casting, as they are very active chemically. The alloy known as lumen metal makes a good hardener for magnesium alloys; thus an alloy of 96% magnesium and 4% lumen metal is a good example of this class of alloys.

Magnesium-copper alloy.—A 10% magnesium-copper alloy finds extensive use as a deoxidizer in brass-foundry practice. This is simply made by first melting the copper in proper proportion under a covering of charcoal, then adding the magnesium in conveniently small pieces, by simply tossing them onto the hot covering of charcoal on the surface of the copper, then stirring them into the copper. Very little magnesium is lost by this method. Alloys of magnesium and copper are of no value for making castings; they are used exclusively as deoxidizers of other metals; the alloy of 90% copper and 10% magnesium, finding application as a deoxidizer of copper, for making copper castings, as the magnesium addition is thus more conveniently made than by the use of pure magnesium.

A very interesting paper entitled "Some Notes on Electron

Metal" was read by J. D. Paton, at a meeting of the Lancashire Branch of the Institution of British Foundrymen, from which we extract the following:

The importance of magnesium would be realized when it is considered that in the world's crust there was 2.68% of magnesium, 47% of oxygen, 27% of silicon, 7.8% of aluminum, 5.46% of iron, and 0.22% of carbon. In comparison with the 5.46% of iron, it should be remembered that the weight ratios were iron, 6; aluminum, 2; and magnesium, 1—in other words, magnesium was a sixth of the weight of iron. Therefore, to get the corresponding bulk, the 2.68 must be multiplied by 6, giving 16.08. Prior to 1914, the world's consumption of aluminum was between 20,000 and 30,000 tons, of which Germany's share was approximately 6000 tons, and during the World War that country had to find a substitute for aluminum. Experience had already proved that magnesium would in part at least, meet the requirements, and the developments that took place during that period resulted in the production of a satisfactory substitute for aluminum in quantities which were reported equivalent to the pre-war consumption of aluminum.

Electron metal was actually recovered from magnesite, and was supplied in ingots to any weight desired; but the larger they were the longer it took to melt, and the greater the gas consumption. For these reasons the standard size was 2 kilograms (4.4 lb.). Each ingot could be broken into two 1-kilo blocks. They were almost identical with aluminum ingots, but size-for-size were only half the weight.

In hardening magnesium, a small proportion of aluminum was added. The 12% copper-aluminum alloy, when compared with the 2% aluminum-magnesium alloy, showed that the alloy would be actually lighter than the pure metal ratio, by the out-of-balance increment in aluminum alloys. The magnesium alloy was 6 to 4 commercially, and 4 to 6 when pure.

The characteristics of the new metal may be summarised thus: Tensile strength (cast), 7 to 10 tons (15,680 to 22,400 lb.); tensile strength (rolled), 10 to 15 tons (22,400 to 33,600 lb.); heat expansion, 0.000027 per linear foot; specific heat, 0.25; and specific gravity 1.74.

Casting magnesium alloys.—The casting of electron metal must be carried out with care. A certain amount of experience with the characteristics of the metal was necessary; but a skilled workman readily acquired this experience and was then capable of producing serviceable castings. The burning of magnesium is a well-known property. In melting magnesium in a furnace much the same thing happened—intense heat was generated, accompanied by a blue flame. There was some danger, but only when the metal was in a molten condition, and it could easily be guarded against if damp were absent.

If overheated, the metal became plastic and had a tendency to absorb gases; therefore, the molds should be kept covered as far as possible, gas and coke fumes must be kept away from it, and it had to be watched and controlled carefully with a pyrometer. The ratio of coke to metal was 500 to 1000 lb., so the heat losses were not very high.

With magnesium in a hot state, the presence of water meant liability to trouble, possibly a series of explosions. There must be no wet sand, and it is essential to have the floor dry. If men are walking about they must do so carefully, and they must not draw a pot too hot; the temperature should be reasonably low, and the metal must not lap the lip of the crucible when drawn. The molds also must be as nearly bone dry as possible. They must not be constructed of any material which held water in a combined form, or in a form which under the pressure and action of the metal would be distilled as vapor and provide an explosion. For that reason the walls should be banked. A sand of high silica content, which did not contain water in its mechanical composition, was essential.

It is necessary to have a series of gates running to and from the casting. The feeders are very thin. Apparently long crystals were formed on the outside, which acted as a sieve for the hot metal which washed through, the dross being held back. When using magnesium oxide as a base, which was heavier than the metal, it was difficult to remove it. The advantage of magnesium oxide in the case of other metals was that its weight was so much less than the metal in which it was held, that it rose to the surface. Magnesium, therefore, made an excellent deoxidizer, but no flux had been discovered capable of expelling the oxygen from the surface of the molten electron metal, and at the same time be harmless to the metal. Magnesium chloride would exclude oxygen, but the objection was that the chloride entered the metal and set up disintegration. Very often a sort of burning on top of the mold occurred, and to stop that a handful of dry sand was spread over the top. To avoid oxidation and get clean castings, Paton had tried bottom pouring, but what happened was that the drops dripping, when shutting off the stream of metal, had a tendency to ignite, with the result that the oxidized particles remained and accompanied the next flow into the mold. They appeared again as oxide which might spoil the casting. The castings should be removed from the sand at a temperature not exceeding 212° F., above which it was brittle.

The color of the castings depended upon the temperature of the metal and the dryness of the mold. A silver color was obtained by casting at the correct temperature into a perfectly dry mold. For thick-walled castings the pouring temperature would be from 1200 to 1256° F.; and for thin-walled castings, 1292 to 1382° F. A blue and silver color was obtained on the castings when the metal

was so hot that it reduced the silicon from the sand, which entered the surface of the metal. When the pouring temperature was correct, but the mold was not dry, the surface of the castings would be gray.

In cleaning castings, wire brushes were used. The dust and grindings were dangerous, and trouble was guarded against by putting finely divided material in an iron box; if the material took fire, it was smothered with dry sand.

If carefully carried out there was no danger in casting such alloys. With dry floors, careful handling, careful gating, and correct heating the castings could be made without trouble.

One great advantage of electron metal is its ductility, especially in a cast form. Ordinary castings were often brittle, and could not be stamped after they were made; but it was possible to cast this metal as a block which could be shaped by stamping. The skin could be case-hardened, and then it could be burnished. The alloy can be machined at three times the speed of aluminum. The metal had been successfully applied in airplane construction. It might be thought that where sparking occurred the magnesium would be a bad metal to use, but the results had been satisfactory. An airplane had been constructed almost entirely of electron, then loaded with gasoline, and sent up as high as possible, then was shot through, so that it dropped in flames to the ground; but though magnesium was supposed to be an inflammable metal, it was the last thing to burn in that test; the wood, the fibers, and everything else on the airplane were burning before the electron ignited.

It appeared that magnesium alloys could be cast in sand molds, but not in chill-molds. Some reaction occurred between the magnesium and the iron, which produced blowing; iron molds, therefore, were unsuited to its reception. Magnesium alloyed well with lead, and alloys containing lead. Its effect was to harden lead, and in the case of lead-sheathed copper cables it was difficult to get the lead covering homogenous enough to keep out water, but by a slight addition of magnesium, nearly twice the strength was obtained, associated with less reaction and corrosion.

Turnings and chips of this metal could be used up, and the best way of doing so was to briquet them and add this material to a bath of the liquid metal. All scrap should be cleaned before it is re-melted. Sand left on the castings when they were re-melted increased the rejects from 2 to 7%. If sand was allowed to remain on the sprues and castings to be re-melted, the rejects would be about 7% the first month, 15% in the second month and 25% in the third month. Trouble from porosity in the case of re-melted metal arose from scabbing, due to the taking up of silicon, from the sand.

There was an important difference between magnesium alloys and aluminum, namely, the latter metal would withstand acids, but not alkalis, but magnesium would withstand alkalis but not acids. The two metals were, therefore, complementary.

Magnesium and mercury.—Magnesium does not amalgamate with mercury at the ordinary temperature, but by shaking the two together in dilute sulphuric acid, amalgamation takes place (Hartley and Phipson, and J. Parkinson). Also by heating them together to nearly the boiling point of the latter, amalgamation also takes place under violent reaction. Such an amalgam, containing 1 part magnesium and 200 parts mercury, becomes immediately dull and swells up on exposure to the air; it decomposes water as vigorously as sodium amalgam (Wanklyn and Chapman).

Magnesium-lead alloys.—Magnesium also combines with lead and zinc, alloys with 5 to 20% being of considerable interest. An alloy of 15% magnesium and 85% lead will rapidly and completely oxidize in the cold (E. A. Ashcroft); and if exposed to atmospheric oxygen and moisture is rapidly converted into a jet-black powder having the composition of magnesium hydrate and lead sub-oxide or its hydrate. The reaction is complete in a few hours. This alloy is useful for removing oxygen from any confined space; every trace of oxygen can be thus removed from any gaseous mixture containing it. For such a purpose the 15% alloy is preferable to one of higher magnesium content, as the richer alloys—35% magnesium and upwards—will not oxidize readily in the cold. An alloy of 35% magnesium and 65% lead finds application for the production of pure hydrogen for aircraft and other purposes. All that is necessary is to digest the alloy under a steam pressure of 100 lb. per sq. in. Many other uses are continually suggesting themselves for such alloys.

ZINC ALLOYS

Zinc alloys have been known for many years. Thus, Walter Graham, in his book *Brassfounder's Manual* published in 1887, mentions "Fontainemoreau's bronzes" as alloys in which zinc predominates, and which are said to answer well for chill molding—that is, for pouring in metal molds by which method the alloys are rendered very homo-

genous. The following table will show the composition of these so-called bronzes:

Composition of Fontainemoreau's bronzes (Graham)

Alloy	Zinc, %	Copper, %	Iron, %	Lead, %
1	90.00	8.00	1.00	1.00
2	91.00	8.00	....	1.00
3	92.00	8.00	....	....
4	92.00	7.00	1.00	....
5	97.00	2.50	0.50	....
6	97.00	3.00	....	....
7	99.50	....	0.50	....
8	99.00	1.00	....	....

Alloys of zinc and iron are of no value commercially; the addition of copper to zinc breaks up the large crystals, when about 10% is added, but such alloys are very weak. They have absolutely no elongation; an alloy of 89% zinc and 11% copper will possess a fine crystallization, but its transverse strength is only 75 lb., compared with 419 lb. for a bar of ordinary cast iron exactly the same size. The addition of iron or lead makes no improvement in the alloys. The only metal that will improve the strength of these alloys greatly is aluminum, but in 1887, the year of Graham's book, aluminum was an unknown metal in brass foundries, therefore, the modern zinc alloys were impossible.

To illustrate the effect of aluminum on zinc alloys, we will take the alloy mentioned containing 11% of copper, with the addition of 2.75% of aluminum, making an alloy as follows: zinc, 86.25%; copper, 11.00%; and aluminum, 2.75%. This alloy was cast into rods of the same pattern as the alloy containing 11% copper only, and also the cast-iron rod, which tested to 419 lb. per sq. in. The alloy with aluminum broke when loaded to 384 lb., and therefore was almost as strong as cast iron. An alloy of 82.75% zinc, 3.45% copper, and 13.80% aluminum, broke at 518 lb., thus being considerably stronger than cast iron.

The foregoing will serve to explain the addition of aluminum to zinc alloys; it greatly increases the strength and

fluidity of the alloy—in fact, without aluminum, the alloys are practically useless, unless they contain a considerable quantity of tin. The series of zinc-copper-tin alloys is used for die-castings, and are found satisfactory for a number of purposes, such for instance as base castings for electric meters. The alloy is, however, improved by the addition of a few hundredths of aluminum, which improves the fluidity of the alloy so that it fills out the molds better. About $\frac{1}{2}$ oz. of aluminum per 100 lb. of alloy is sufficient for this purpose. An example of this class of alloys is 88% zinc, 6% tin, and 6% copper; which is a strong alloy of fairly close grain.

Use of hardeners.—As in the case of all other alloys, the zinc-base alloys are of better quality when made by the use of a hardener which introduces the more refractory metals. The alloy known as lumen bronze is usually made in this manner. This alloy was patented (U. S. patent, 778,398) by Christopher Bierbaum of Buffalo, New York, on December 27, 1904. The alloy was specified as follows:

Composition of lumen bronze

	Per cent
Zinc.....	86.00
Copper.....	9.90
Aluminum.....	4.00
Magnesium.....	0.10

A modification of this alloy is zinc, 84.50%; copper, 10.50%; and aluminum, 5.00%. The modification is used more particularly for sand-casting purposes. The properties of lumen follow:

Properties of lumen bronze

	Chilled alloy	Sand-cast alloy
Tensile strength.....	40,000 to 45,000	32,000 to 35,000
Elongation.....	None	None
Brinell hardness.....	119 to 124	114 to 119
Specific gravity.....	6.9	
Weight; cubic inch....	0.249	
Shrinkage, inch.....	$\frac{3}{84}$	
Compressive strength, lb	80,000	

The alloy has found extensive use for bearings, but should not be used where it will be subjected to zero temperatures, otherwise it will break.

Zinc-base alloys are also used for the production of certain classes of die-castings, and a typical alloy, according to Charles Pack, is the following:

Typical zinc-base die-casting alloy

	Percent
Zinc.....	84.50
Tin.....	9.00
Copper.....	4.50
Aluminum.....	2.00

Approximately 85% of all die-castings made in the United States and Europe are from zinc-base alloys, 10% from tin-base alloys, and 5% from lead-base alloys. The following table shows alloys used for die-casting purposes:

TABLE 76.—Composition of die-casting alloys

Zinc %	Copper %	Tin %	Aluminum %	Lead %	Antimony %
83.00	10.00	5.00	2.00		5.00
90.00	6.00	1.00	3.00		
85.00	5.00	5.00	.....	
87.00	3.00	10.00			
85.00	4.00	8.00	3.00	2.00	0.30
73.75	5.25	14.75	6.25		
72.70	5.00	19.00	1.00		
46.20	2.60	30.80	29.40		

Cothias metal.—This is the base alloy or hardener of a series of zinc-base alloys. The composition of cothias metal according to Emil B. Horne is 66.70% copper and 33.30% tin. This is alloyed and cast into small ingots. For small castings the following mixture was used: cothias metal, 11.75% and aluminum, 88.25%. The mixture more commonly used consisted of 70.00% zinc, 15% aluminum, 7.50% tin, and 7.50% cothias metal. The cheapest alloy consisted of 85.60% zinc, 0.40% aluminum, 7.33% tin, and 6.67% cothias metal. The alloys were cast in metal molds, the entire operation being similar to that followed at present in the case

of aluminum bronze. The metal was melted in crucibles, dipped from the pot, and poured into the molds which were held together with thumb-screws. Inasmuch as dies or metal molds were used for the reception of the molten metal, the product was entitled to the term die-castings; and the same holds good in the case of aluminum bronze, which is melted in small crucibles and then poured into the die-molds. Such castings are die-castings, because dies are used for molds; the fact that pressure is not used on the metal to make it flow to every part of the mold does not enter the operation in any way. In the case of aluminum bronze it is not necessary to put pressure on the metal to induce it to flow, as the metal is sufficiently fluid to run perfect castings.

Zinc-bismuth alloys.—At temperatures which do not materially exceed its fusing temperature (806° F.), zinc alloys only to a limited extent with bismuth. According to Matthiessen, zinc dissolves at the utmost 2.4% of bismuth, and bismuth, at the utmost, 14.3% of zinc. On the other hand it has been found by W. Spring and L. Romanoff that at 1562° F. both metals dissolve in every desired proportion.

Zinc-lead alloys.—With lead, zinc alloys only to a limited extent. Commercial zinc obtained by distillation from lead-bearing ores may contain up to 5.6% of lead. If, however, for the purpose of refining, such zinc be kept liquid for some time, a portion of the dissolved lead separates in the form of lead-zinc with about 3% of zinc, and, being the heavier constituent, deposits on the bottom. The remaining zinc then contains, as a rule, not much over 1% of lead.

Zinc-silver alloys.—Zinc alloys with silver, however, more readily, and this behavior of zinc, on the one hand, towards silver, and, on the other, towards lead, is made use of in smelting works to withdraw the content of silver from argentiferous lead. Zinc is added to the melted lead whereby an insoluble zinc-silver alloy is formed. This rises to the surface and is skimmed off for further working.

Zinc alloys readily with copper, tin, gold, nickel, and antimony.

CHAPTER XXV

DIE-CASTINGS

DIE-CASTINGS are castings made by pouring metal into molds that shape it into what might be termed "finished parts"—that is, the castings made by this process do not require machining before they can be used. In fact, the object of die-casting is to produce castings so exact in dimensions that they save the cost of machine work required in the case of ordinary sand-made castings. While the die-casting itself may cost considerably more than a similar part produced in a sand mold, the castings are an economy owing to the skilled labor saved, as they are used direct from the molds.

There are two classes of die-castings, namely, pressure-run castings and gravity-run castings. Included in the latter term might be such castings as zinc figures and statues, lead figures and toys, battery plates, dental appliances, boiler plugs, and all kinds of castings cheaply made by running them in a metal mold; but the tendency is to confine the term to machine parts that are cast to a given size with a high degree of accuracy, this excluding the rougher class of castings, which are more fittingly described as chill-castings. The fusible metals are the most easy to cast in metal dies, and probably the alloys most used are those having a zinc base, as they can be made harder and more rigid than the alloys with a base of tin or lead. Alloys of aluminum are also made into die-castings, also alloys having copper as a base, although of this latter class aluminum bronze is the only one that is being die-cast with any degree of success.

Die-casting has its limitations, for while it is possible to make some very difficult pieces by this method, they must show a saving over similar parts made from machined sand

castings. Die-castings of the fusible alloys can be made within a limit of 0.002 inch of standard size without great difficulty. A limit of accuracy within 0.0005 inch is possible, but rather costly owing to the attention the dies must receive in order to keep them within those limits. When specifying the accuracy of die-castings, very close limits should be dispensed with where possible to keep down the cost of the castings.

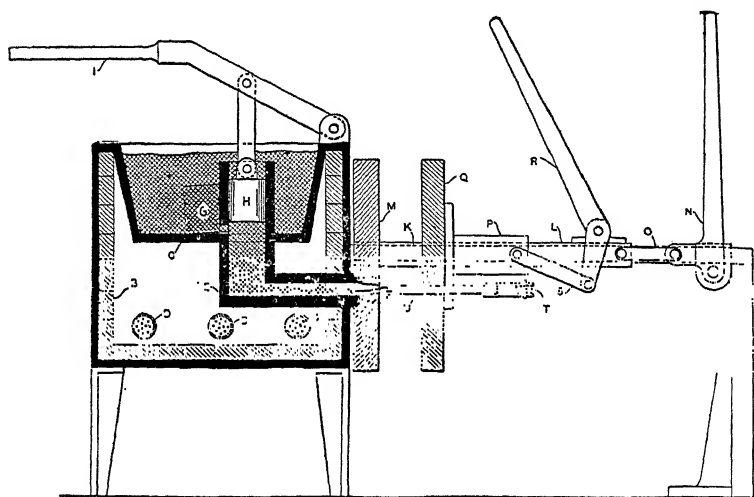


Figure 93.—Section of Soss die-casting machine.

Die-casting fusible alloys.—Regarding the die-casting of fusible alloys, a very interesting paper was presented by Alfred Uhlman, and reproduced in *Gieserei-Zeitung*, from which we take the following excerpts:

The process of die-casting had been employed before the War for casting parts of scientific instruments, objects used in the optical industry, motor-car fittings, parts of clocks, apparatus used in telephony, and illuminating engineering; and during the War, for objects used in munition work, and for military purposes where a very large number of the same castings had to be produced.

The metal employed was an alloy of tin and zinc having a low melting point, but with certain modifications the process can be used for casting objects in aluminum, brass, copper, bronze, and iron. Two different types of apparatus are illustrated in figures 93 and 94, but as will be noted, both designs have the pump and

crucible in one, in order to maintain the molten metal at an even temperature. As, in this case, the pump cylinder and piston are made of cast iron of a special grade, the apparatus can only be used for temperatures not exceeding 500°C . If, therefore, the metal to be cast has a higher melting point—like aluminum or brass (1217°F . and 1886°F .)—a different method has to be employed. To deal with such metals, compressed air was at first tried, which was admitted to the air-tight crucible, and spreading over the bath forced the metal into the permanent die, which was also made air-tight, as shown in figure 95. This method, however, did not give satisfaction. After a few trials it was found that the compressed

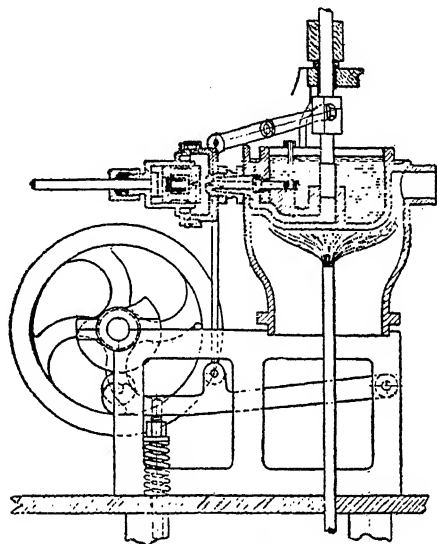


Figure 94.—Die-casting apparatus.

air inflated and deformed the crucible, and thereby destroyed the air-tight joint, to maintain which was in itself a difficult problem, owing to deformations caused by expansion and contraction under the varying degrees of temperatures. To overcome this difficulty, working with a vacuum in the die was substituted for the compressed air in the crucible, and the molten metal was sucked into the die. A variety of apparatus was developed upon this principle, but here again the expansion and contraction caused difficulties. The dies were deformed, and it was extremely difficult to maintain an efficient vacuum owing to leakages at the joint. At the outset, the dies were almost exclusively made of tool-steel, but later various other materials were tried, such as hard glass, marble, serpentine, etc., but these materials can only be used for casting very small objects, and then without using cores or screw-threads.

Material for dies.—Cast iron, high in silicon, was, after all, found to be the most suitable material for the dies used in casting aluminum, brass, and such alloys, because it was not attacked at all, or

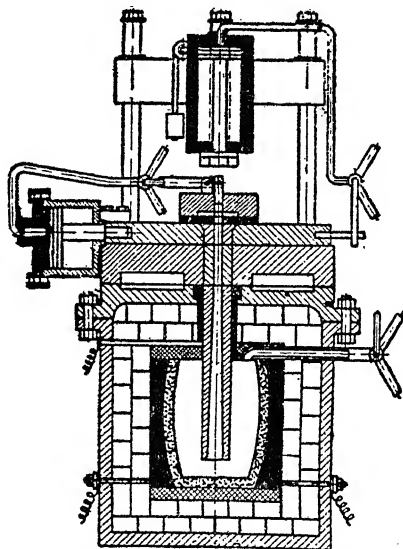


Figure 95.—Apparatus used in casting bronze.

only slightly, by the gases given off by the molten metals. Using a vacuum, however, did not turn out an unqualified success, because at first it was impossible to keep up a constant vacuum in

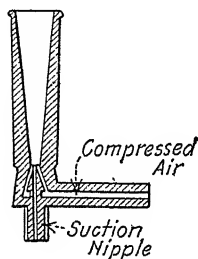


Figure 96.—Injector for producing a vacuum.

the mold with a suction pump, and to renew the vacuum afresh for each casting occupied too much time. Mr. Uhlman then hit upon the idea of producing a vacuum by means of the injector shown in figure 96, which answered very well. It created the vacuum

very gently, and maintained it uniformly so that the molten metal was quietly and uniformly sucked into the die. By this means sound castings were produced without air-holes, and free from oxides, which had given considerable trouble when the vacuum was produced by a pump.

A vacuum-casting machine on this principle was devised, and can be used for casting aluminum, brass, red metal, bronze, and even cast iron without any trouble, and thus marked a great step forward.

The following table gives the composition of some zinc-base die-casting alloys:

TABLE 77.—Zinc-base alloys used for die-castings

Name	Zinc, %	Tin, %	Lead, %	Copper, %	Anti- mony, %	Alu- minum, %
Shonberg's.....	87.00	10.00	.....	3.00	.....	.....
Liddel's 1.....	87.50	.....	.....	6.50	.....	6.00
" 2.....	90.00	.....	.....	5.00	.....	5.00
Lumen bronze.....	86.00	.....	.....	10.00	.....	4.00
Salge's bronze.....	84.00	10.00	1.00	4.00	1.00	.....
Fenton's.....	79.00	14.00	.....	6.00	1.00	.....
Ledebur.....	85.00	.....	.....	5.00	10.00	.....
" 2.....	76.00	17.50	.....	5.00	1.50	.....
" 3.....	74.00	15.00	.....	5.00	.....	6.00
" 4.....	74.00	12.00	.....	11.00	.....	3.00
" 5.....	73.00	10.00	.....	5.00	2.00	1.00
Standard.....	85.00	8.00	.....	4.00	.....	3.00
.....	83.00	5.00	.....	10.00	.....	2.00
.....	90.00	1.00	.....	6.00	.....	3.00
.....	85.00	5.00	.....	5.00	.....	5.00
Strong, hard.....	86.50	.....	.....	10.75	.....	2.75
Hard.....	82.75	.....	.....	3.50	.....	13.75
Meter bases.....	79.95	6.00	.....	6.00	.....	0.05

Cothias metal also used for die-castings is made by first making a hardener as follows: copper, 66.70%; melt and add tin, 33.30%; then pour into ingots. Three alloys are known as cothias metal, and are made as follows:

Alloys known as cothias metal

	No. 1, per cent	No. 2, per cent	No. 3, per cent
Aluminum.....	88.25	15.00	0.40
Hardener.....	11.75	7.50	6.65
Zinc.....	.....	70.00	85.60
Tin.....	.....	7.50	7.35

Lead and tin-base alloys.—Other alloys used are those having a base of tin, and those with a base of lead, examples of which can be found among the alloys listed under those metals. Any good flowing babbitt metal can be used to make

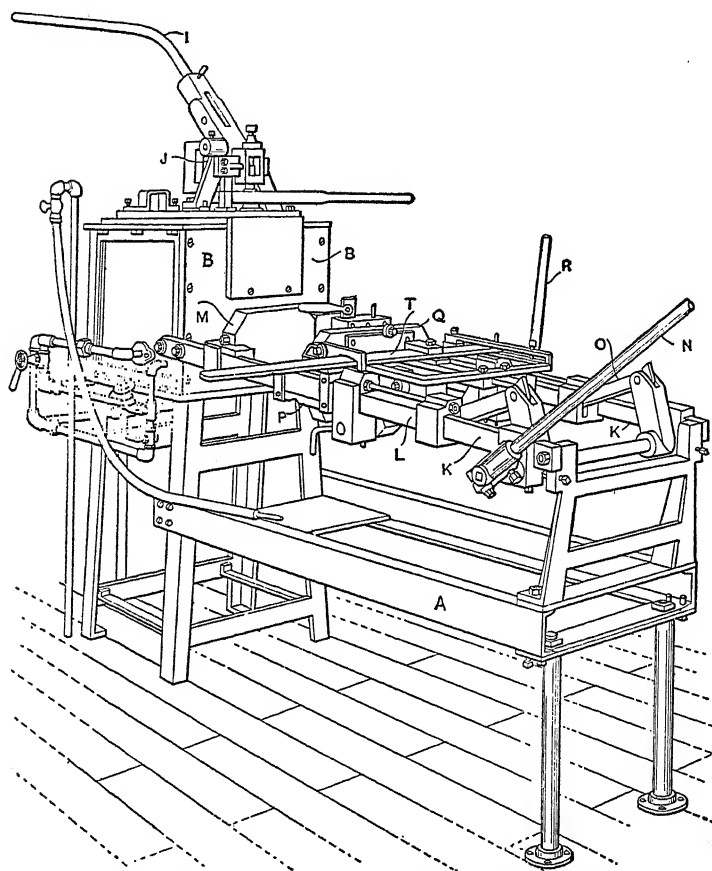


Figure 97.—Details of the Soss die-casting machine.

die-castings. The tin-base alloys are the most expensive and the lead-base alloys the cheapest, but both classes are comparatively soft and have low melting points.

The Soss die-casting machine.—The machine shown in figure 93, which was used to illustrate the article by Uhlman, was developed and is manufactured and sold by the Soss

Manufacturing Co. of Brooklyn, New York. A complete view of the machine is shown in figure 97, where *A* is the base and frame of the machine, and *B* is the metal heating chamber. In the sectional view (figure 93), the cylinder *E*, partly submerged in the tank *C*, in the molten metal which is heated by the burners *D*, which are served with gas through the pipe connections visible in figure 97. The cylinder *E*, in

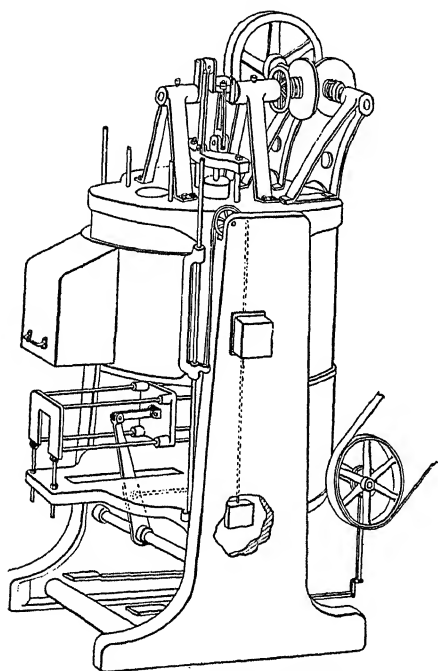


Figure 98.—Semi-automatic die-casting machine.

figure 93, has its larger, vertical diameter fitted with the piston *H*, manipulated by the lever *I*, and the bottom end of the cylinder opens into a horizontal passage which extends through the walls of the furnace and is closed with a valve *F*, to retain its molten contents. The melted metal flows from the tank to the cylinder through the small passage *G* in the wall of the cylinder. The latter, it will be noted, gets the heat from two of the burners, while the tank is served with

only one, which has the effect of always keeping the metal in the cylinder and passage at the proper degree of heat, while the contents of the tank are less strongly heated.

When the piston is forced down, the metal in the cylinder, if the valve *F* is opened, it is driven into the dies, and after its stroke the piston ascends automatically through the medium of a spring. The other end of the machine is occupied with the dies and their operating and aligning mechanism; the movable parts being carried by the horizontal square rods, *K* (figures 93 and 97). These movable parts consist of two die-plates, *M* and *Q*. Both these plates are movable, both together and independently, and they are held in alignment by the sleeves *P* and *K*, one of which slides within the other,

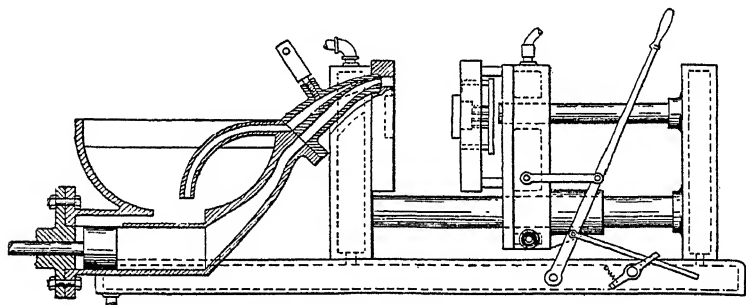


Figure 99.—Improved die-casting machine (Tenca).

and both slide on the square sustaining bars. The levers *R* and *N* operate the die-plates, and to the latter the dies are attached, but are not shown in the illustration. By pulling lever *N*, the die-plate *M* is pulled away from the opening of the molten metal ejecting cylinder (the illustration shows it tight against the same), a metal-tight connection is made by making the cylinder opening conical and perfectly fitting a corresponding depression in the die-plate as shown. The nozzle-shaped opening through the die-plate *M* connect to the dies which are mounted on the plates. The rod *U*, extending through the die-plate *Q*, is the sprue cutter.

When the machine is operated, the burners are lighted and the tank and cylinder are heated, and the ready mixed molten metal is poured into the tank. Three men usually operate

this machine, one attending to the metal supply and compression lever, while the others stand on either side of the machine and manipulate the dies and sprue cutter and remove the castings, and clean the dies with compressed air as required. When the metal in the machine is ready, the dies are closed by lever *R*, and the mold is moved by lever *N*, up against the cylinder opening. Valve *F* is now opened, and at the same time the man at the lever gives it a quick, hard pull, forcing the metal into the dies. The metal by this machine is squirted into the dies, which movement is open to criticism in the case of all metals containing aluminum. The



Figure 100.—Crucible tilting furnace
(Monarch type).

valve *F* being closed, the mold is carried away from the furnace by lever *N*; the sprue-cutter lever is manipulated which cuts off the sprue and pushes it out of the nozzle-shaped opening in *M*, and it drops to the floor. The dies are opened by lever *R*, and the finished casting is removed.

Die-castings are made at a speed that may vary from 10 to 60 pieces per hour, depending upon their size and shape. When more than one casting can be carried by each mold, the output of castings is greatly increased.

The foregoing description will serve to give a general idea of the methods adopted for making die-castings of the softer or more fusible metals. Improvements on the above

process have been many, some of them taking the direction of reducing labor costs by automatic operation of the machines. Thus in figure 98 is shown a casting apparatus patented by H. H. Doehler, who in his specification refers to the fact of automatic die-castings being successfully applied to the casting of type and bullets, but in the case of commercial work using large heavy dies the automatio

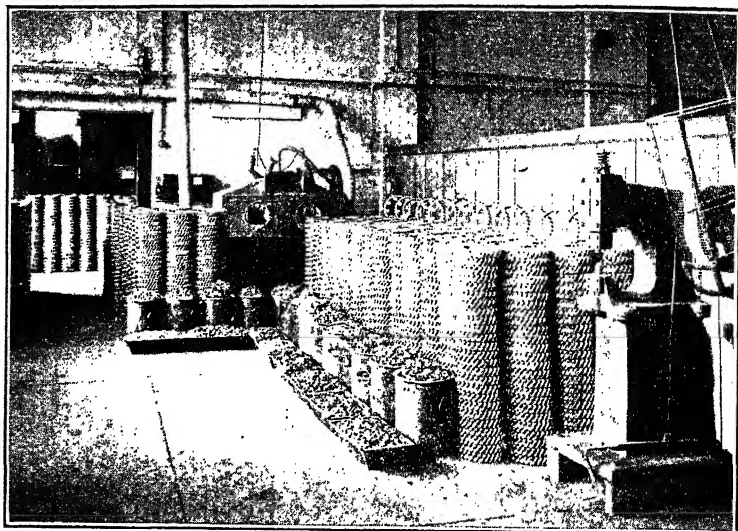


Figure 101.—A shipment of die-cast worm-gears (courtesy Buffalo Bronze Die Cast Corp.).

machines have been found of no value, particularly where the dies contain one or more movable cores. This machine, he states, is automatic to the extent of being operated similar to the punch-press used in sheet-metal working, and the manner in which the machine works is very fully set forth in the patent specifications (U. S. patent, 1,249,919, Dec. 11, 1917).

A machine of a different type is that of Louis P. Tenca of Cleveland, Ohio. This machine is shown on figure 99, and it will be noted that it is of rugged construction, also it is designed so that the parts of the machine surrounding the dies are water-cooled to facilitate the rapid production of

castings. In describing his invention, the inventor states that it is designed particularly for use in a machine for casting under pressure; also:

It is well known that the difficulty with this method of casting is in the escape of the air confined in the empty mold chamber, that if this air fails to escape, it diffuses through the molten metal, producing a casting containing many blowholes, and even if so well diffused that no blowholes are produced, it nevertheless renders the casting lighter and weaker than is desirable.

His invention, he claims, eliminates this difficulty, and also provides means for accurately controlling the tempera-

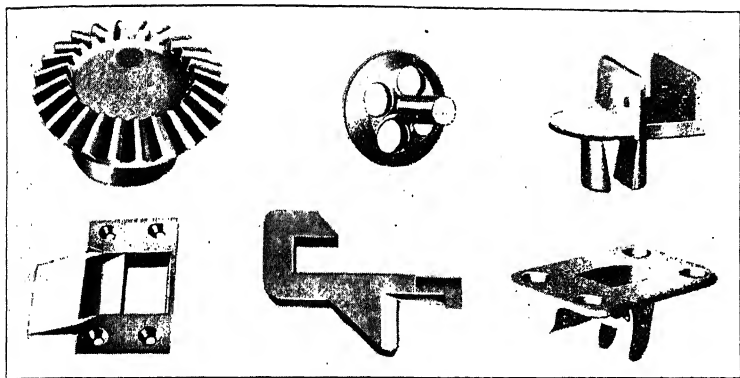


Figure 102.—Specimens of bronze die-castings (courtesy Buffalo Bronze Die Cast Corp.).

ture of the mold chamber. The above sets forth the entire trouble encountered in making die-castings, and for that reason is inserted here. For a further description of this invention the reader is referred to the specifications of U. S. patent 1,226,408 of May 15, 1917.

Bronze die-castings.—On account of their high melting point, copper, bronze, or brass cannot be melted in metal containers as is the case with the alloys of zinc, lead, and tin, because the metal vessel itself would melt; or if it did not actually melt at the temperature of the molten bronze or brass, it would dissolve therein like nickel in copper. Other metals that dissolve in molten copper alloys are iron, steel, cobalt,

and alloys of chromium and nickel. The only melting vessel that can be used is a crucible of refractory material, and the ordinary graphite crucible is generally used; also it would be possible to melt in a non-crucible furnace of the type shown in figure 61, or in a tilting crucible furnace as shown in figure 100, when large quantities of metal are required. The use of crucibles either as melting or pouring vessels renders it difficult, as noted by Uhlman, to apply pressure to the metal; or even to fill the molds by vacuum unless produced by such a contrivance as the injector illustrated. The more direct way then is to run in the metal by gravity, which brings up the problem of feeding the shrinkage of the metal to produce solid castings. In the case of bronze castings made in die-molds, the holes that are liable to be found are not due to mixing the molten metal with the air in the mold, because the metal is not squirted in under pressure, but gently rises from the bottom and fills up the mold. The difficulty of holes is due to shrinkage of the metal, and in the case of heavy castings this can be overcome by the use of insulated risers, which have the fault of retarding production, owing to the time consumed in solidifying.

However, this problem has been very largely solved by some manufacturers. Thus figure 101 shows a large shipment of worm gears, and some smaller castings of various shapes, at the plant of the Buffalo Bronze Die Cast Corporation, Buffalo, New York. All of the castings shown are die-castings of bronze made by the gravity process. Some of the small castings in the pans are shown in greater detail in figure 102. The gears weigh 12 lb. each, and are cast as shown in the illustration—that is, the teeth have not been machined, but were produced by the molds, which are all metal. The Buffalo Bronze Die Cast Corporation was organized in 1918 by Thomas W. H. Jeacock, who is now president, and Nathaniel W. Meloan, vice-president and general manager, with a capital of \$15,000, which since then has been twice raised, until at present it has reached \$245,000 all paid in. The company is constantly experimenting with a view of

enlarging the size of the castings they can produce by the die-casting method, and they have started to produce one gear weighing from 38 to 40 lb., of a special alloy of their own invention. Generally, the alloy made by this company and used for the castings shown consists of 90% copper and 10% aluminum, a special de-gasifier being used devised by the author. Some of the bronze castings have been cast in two pieces, with an outside thread that had to be in perfect alignment when the two parts were assembled, and using a thread of 20 pitch. Holes are cored with metal cores to as great a degree of accuracy as with the fusible metals, and teeth on bevel gears up to 4 inches in diameter are cast to a degree of accuracy, plus or minus of one-thousandth of an inch. The bevel gears shown are turned out at the rate of 700 to 1000 per day.

From the above notes some idea will be gleaned of the progress being made in making bronze castings in accurate molds. Regarding the life of the molds or dies, some have turned out over 35,000 castings; the larger dies do not last as long.

The difficulty that arises in making die-castings, whether of bronze or the fusible metals, is to get them free of cavities. The application of pressure has been found of great advantage wherever it can be applied commercially. When this is not possible some other method must be adopted, and in some cases this has taken the form of cooling the body of the die with water, which is caused to circulate through them, while some body of metal is so placed that congealing after the casting, it can seep down into the latter and fill up shrinkage cavities. Thus, one by one the difficulties attendant on the production of finely finished castings are being overcome. In the casting of aluminum alloys there was no great advance in making die-castings until the proper alloys were found. The alloys previously used for making sand-castings were too tender at temperatures above normal, and cracked in the dies. The remedy was to increase the copper content, up to 14%. Alloys of aluminum and silicon were invented by Aladar

Paxx of Cleveland, Ohio. The silicon content ranges from 5 to 14%, and is known as "Alpax metal" or "Aladar" in the United States in honor of the inventor. In Germany such alloys are known as "silumin" from "silicon and aluminum," the two principal constituents.

CHAPTER XXVI

SOFT SOLDERS AND BRAZING ALLOYS

A SOLDER, according to a concise definition given in the "Chemical Dictionary" * for 1919, is an alloy consisting of two or more metals having a melting point below that of any of the constituent metals, and used for joining other metals together by filling a joint or covering the juncture, as distinguished from brazing and welding.

Ordinary solder consists of equal parts of lead and tin, and melts at $188^{\circ}\text{C}.$; whereas the melting point of lead is 327° , and tin, 230° . Solders with melting points down to 95° are composed of lead, tin, and bismuth.

Solders are really metallic cements applied by being melted onto the surfaces to be joined to form a thin film or coating which is firmly adherent when cold.

These metallic cements must possess the property of alloying with the surfaces to be joined, otherwise they would not adhere. When two pieces of brass are joined by a tin-lead solder, it can be shown that the solder has penetrated into the brass and is firmly "rooted" to the surface. After the two parts are joined, if force is employed to pull them asunder, the surface of the brass will not suffer, as the parting will occur through the film of solder between the two surfaces. The solder is the weakest part of the joint, because soft solder is inherently a weak alloy; thus the thicker the film of solder the more easy it will tear through, so that in joining two surfaces with solder, the thinner the film the stronger will be the joint. On account of this, when two surfaces are joined by "sweating," as the method described is termed, it

* Chemical Catalog Co., New York City, edited by F. M. Turner, D. D. Berolzheimer, W. P. Cutter, and John Helfrich.

is usual to apply pressure to squeeze out the surplus solder from between the joint.

It will be evident that the alloy used as a solder or cement must melt at a lower temperature than the metal of the parts to be joined. In the case of some alloys, such as Britannia or pewter, the difference in melting points between the solder and the metal to be joined is so small that skill is required to apply the solder without melting away part of the article soldered.

According to Milton L. Lissberger,* solder is a mechanical mixture of lead and tin, and when a bar is passed under a buffing wheel—if it is as low a grade as 30% tin and 70% lead—the buffed surface will assume an appearance practically identical with a bar of second quality or reclaimed tin, while the buffings when subjected to analysis will be found to be almost pure lead. The two metals tend to separate, and it is the contention of Lissberger that in order to get a good mechanical mixture the bath of metal must be stirred by hand for a period of 5 or 6 hours, irrespective of the quantity of material being mixed, and also irrespective of the proportion of tin in the mixture, whether 60%, or as low as 30%. An ordinary pig of solder about 1.25 inches in thickness was sampled by drilling in five places from top to bottom of the section, each hole being equally spaced, the top drilling being as near to the top as possible and the bottom drilling as near to the bottom as it was possible to drill. Analysis of the samples showed a tin content at the top of 59.06%; the one under it, 52.99%; the third, 38.43%; the fourth, 39.07%; and the fifth, 42.62%. The strongest solder, according to the same authority, is one containing about 46% of tin and 54% of lead, with about 0.25% antimony in place of that amount of tin.

Types of solders.—While there are many different names applied to solders, such as tinman's, plumber's, soft solder,

* Transactions American Institute of Mining and Metallurgical Engineers, vol. 60, p. 192.

hard solder, silver solder, spelter solder, and gold solder, they may be divided into two classes, namely, hard solders and soft solders. The two classes differ materially from one another; the hard solders melt at a red heat or above, and their color may be varied to match that of the objects to be soldered, thus making an invisible joint; while the soft solders melt below a red heat, their color is always white, and they are comparatively soft and weak.

Soft solders.—These solders theoretically consist of tin and lead in different proportions; sometimes special purposes will demand that the tin be in excess of the lead, then for other work the lead has to exceed the tin in the alloy. A large proportion of the soft solders in use are made from scrap or secondary (reclaimed) metals, and will contain impurities, particularly antimony. Some authorities contend that a solder containing around 2% of antimony has a more saleable appearance than a solder made of the pure metals in the proportion of 50% each. A solder containing 46% tin, 2% antimony, and 52% lead, will produce a better appearing bar than a 50-50 lead-tin solder.

Soft solders may be divided into three types of alloys, namely, (1) those that contain more tin than lead, (2) those with equal parts tin and lead, and (3) those containing more lead than tin. The first is noted for fluidity; the second is ordinary solder; and the third is "wiping solder," and is used for wiping joints of lead pipe, for which it is peculiarly suited, because, in passing from the liquid to the solid state it assumes a pasty condition, and at this stage can be spread, wiped, or smeared onto any object to which it will strongly adhere when cold.

Shapes of solder.—Figure 103 shows some of the commercial shapes of solder. No. 1 is a triangular bar; No. 2 is warranted to be half tin and half lead; No. 3 is "commercial" half and half, and will contain antimony; and No. 4 is a shape known as "capping bar." In addition to these shapes, solder is put up in rectangular ingots, and also in the form of wire and ribbon.

Fluxes.—In all soldering processes the following conditions must be observed: First, the surfaces to be united must be smooth and chemically clean; and secondly, the contact of air must be excluded during the process of soldering. Both of these conditions are attained by the use of a flux, which is a necessary adjunct to the soldering process. The word “flux” is from the Latin, and means “to flow.” The action of the flux is to dissolve the film of oxide that coats

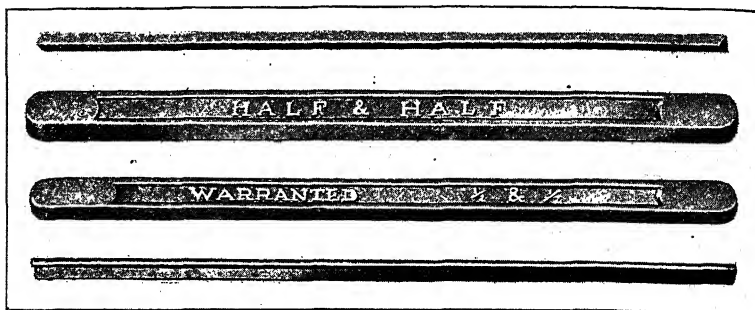


Figure 103.—Shapes of bar solder.

the surface of the metal to be soldered, making it “chemically clean”; it also cleans the surface of the solder, thus permitting the two alloys to come into intimate contact, or to flow together, when an alloying action takes place. For soft solders, a flux extensively used is the following which is permitted by the Code of the National Board of Fire Underwriters:

Flux for soft soldering.

	Parts
Zinc chloride.....	42
Alcohol.....	33
Glycerine.....	25

The zinc chloride should be fused; it is first dissolved in the alcohol, then the glycerine is added. The flux is corrosive, and is not suitable for soldering very fine copper wire. Another very satisfactory soldering acid is made by taking 3 quarts of hydrochloric acid, and dissolving therein as much zinc as

it will "cut"; next dissolve 6 oz. of sal-ammoniac in one pint of warm water, and in another pint of water dissolve 4 oz. of tin chloride. Mix the three solutions, and if any cloudiness is seen in the liquid, clarify it by adding a few drops more of hydrochloric acid. A non-rusting soldering fluid is made by dissolving zinc in hydrochloric acid until it is saturated (killed), then removing excess zinc and filtering the liquid and adding one-third its volume of commercially pure ammonia (26° Baumé), and dilute with a little water. Many other substances are also used as soldering fluxes, the most important of which it may be well to discuss.

Soldering fluids.—Dilute mineral acids are generally used for pickling the places to be soldered, hydrochloric acid being chiefly employed for the purpose. By touching the place where the solder is to be applied with a brush dipped in dilute hydrochloric acid, the oxide is at once dissolved and the melted solder spreads rapidly over the surface. Hydrochloric acid is used on zinc as well as on tin. The combination formed by the solution of zinc in hydrochloric acid is, however, very volatile in the heat imparted to the metal by the soldering iron, and a considerable quantity of vapors are evolved, injurious to the health and to the metal of the soldering iron. It is, therefore, important to have good ventilation in the shop.

Instead of dilute hydrochloric acid, the so-called soldering fluid is often used. It is prepared by dividing a certain quantity of hydrochloric acid into two equal parts, compounding one of these parts with pieces of zinc, and leaving it in contact with an excess of zinc until the development of gas (hydrogen) has ceased. The other portion of acid is compounded with ammonium carbonate until no more effervescence, due to the escape of carbon dioxide, takes place. The two liquids are then combined. In place of the saturated solution of ammonium carbonate, a solution of sal-ammoniac in water may be used, equal volumes of the zinc solution and sal-ammoniac being in this case taken for the preparation of the soldering fluid.

For brass articles, ammonia alone is frequently used, which acts by reducing the layer of oxide on the surface of the metals. As fluxes for coarser work, turpentine, rosin, and a mixture of sal-ammoniac and olive oil are also used.

The composition known as "hard-soldering fluid" consists of a solution of phosphoric acid in alcohol. It is prepared by dissolving phosphorus in nitric acid, evaporating the solution to expel any excess of nitric acid, and mixing the syrupy mass with an equal quantity of strong alcohol. The phosphoric acid dissolves the layer of oxide, the combination formed melting under the soldering iron, and is displaced by the melted solder which now comes in contact with the bright metallic surface. The hard-soldering fluid can be advantageously used in soldering copper, as well as brass, bronze, and nickel silver. Phosphate of ammonia or soda is also used in soldering copper.

The composition known under the name of "soldering fat" may be prepared by introducing powdered rosin in melted and strongly heated tallow, and adding sal-ammoniac. The mass is stirred until homogeneous, and is then allowed to solidify.

For hard soldering, substances are used that dissolve the layer of oxide, and form with it a glass-like combination which is melted by the heat and forced out by pressing the soldered pieces together. The best-known agent of this kind is borax, which readily dissolves the oxides in consequence of the excess of boric acid it contains. For higher temperatures, readily fusible glass, finely pulverized, also does good service, the fused glass dissolving the oxides. A solution of water-glass (sodium silicate) also answers the purpose, and is frequently used in hard soldering.

A better flux for hard soldering is quartz sand (silica) and some decomposed soda. Quartz sand consists of silicic acid, and the soda used is sodium carbonate. Both of these substances on coming together in a strong heat combine to form sodium silicate, which, if silicic acid be present in excess, dissolves the oxides. For very high temperatures, as in weld-

ing iron, the use of pure quartz sand alone suffices. By strewing the sand upon the red-hot iron, placing the other piece of iron—also red hot—upon it, and uniting both by vigorous blows of the hammer, the combination of the silicic acid with the ferric oxide formed on the surfaces of the pieces of the metal is pressed out in a fluid form, and the two surfaces of iron having become bright, will unite.

Soldering copper and brass.—In soldering these or similar metals with soft solder, many workmen use the soldering iron exclusively; while in many cases a better joint may be made by carefully filing the places to be soldered so that they fit accurately, applying soldering fluid, and laying a piece of thin tin-foil between them. The parts are then bound together with wire and held over the lamp until the tin-foil is melted. Solders 19 and 21 in the following table may be recommended for this purpose. The fusing points given in the table may be of value in case the same piece of work requires several soldering joints. If, for instance, a joint has been soldered with tin-solder No. 5, an adjoining joint may, without hesitation, be soldered with solder No. 16, the melting points of these two solders being far apart.

Navy Department specifications.—The Navy Department specifies that the solder shall consist of practically equal amounts by weight of lead and tin; that new tin shall be used—Straits, Malacca, or Australian—and commercially pure new lead. Any bar selected at random from a delivery of solder must contain by analysis not less than 99.8% total tin and lead; the tin shall be between 49 and 51%; antimony, not more than 0.10%; and zinc, none.

Slicker solder.—It will be noted from the above table that the solder having the lowest melting point is the one with 66% tin, and 34% lead. This is also known as “slicker solder,” and it is sometimes made from ordinary half and half by heating it gradually on an inclined iron plate when the eutectic runs out.

Solder for porcelain.—A solder for use on porcelain and enamelware patented in Great Britain by W. B. Johnson

(British patent 153,444, Jan. 19, 1921), consists approximately of 30% tin, 60% lead, and 10% zinc. The solder is applied to the glazed surface of the enamel, or to both enamel and any exposed surface of the iron, by means of a steel brush, without the use of a soldering iron or flux. The surface is cleaned and brightened, the vessel is heated over gas, and solder is applied until the surface is tinned, after which more solder may be applied.

Tin as a solder.—Pure tin is the simplest of all soft solders, and is frequently used for soldering fine utensils of tin. Only pure tin should be used, as the presence of foreign metals, especially iron, considerably increases the melting point. Tin solder is generally employed in the form of semi-cylindrical bars or very thin prisms. For soldering delicate work, tin-foil made from pure tin is frequently used. The surfaces being thoroughly cleansed, and, if necessary, well fitted together by filing, a piece of tin-foil is placed between them. They are then firmly bound together with wire and heated in the flame of a lamp or Bunsen burner, or in the fire, until the tin melts and unites with both surfaces. Joints carefully made may be united in this way so neatly as to be invisible.

Bismuth solder is composed of 1 part bismuth, 1 part tin, and 1 part lead. It melts at 284° F. As will be seen from the composition, it is more expensive than ordinary solder on account of the bismuth. It is, however, well adapted for certain purposes, as it is very thinly-fluid and considerably harder than ordinary solder.

As previously mentioned, every readily fusible metallic composition can be used for soldering, and consequently the fusible alloys of cadmium and of bismuth might be classed with the soft solders. They are, however, only used in exceptional cases on account of their high cost.

In table 97 the melting points of lead-tin alloys are given.

Autogenous soldering.—The process called “autogenous soldering” takes place by the fusion of the two edges of metals themselves without interposing another metallic alloy

as a bond of union. The process is possible with the majority of metals and alloys—even the refractory ones—and though it does not actually come under this chapter, it will be briefly described. The union of the metals is accomplished by directing oxy-hydrogen jet upon the two surfaces or edges to be soldered together. Metals thus joined together are much less likely to crack asunder at the line of union by differences of temperature, flexibility, etc., than when the common soldering process is employed. This method of soldering is especially of great advantage in chemical works for joining the edges of sheet lead for sulphuric acid chambers and concentrating pans, because any solder containing tin would soon corrode. When two edges of sheet lead are thus joined the process is termed “lead burning.”

TABLE 79.—*Melting points of lead-tin alloys*

Lead, %	Tin, %	Melting point, °F.	Brinell hardness number
100.00	0.00	621.0	3.9
90.00	10.00	577.4	10.1
80.00	20.00	532.4	12.2
70.00	30.00	481.0	14.5
60.00	40.00	446.0	15.8
50.00	50.00	401.0	15.0
40.00	60.00	368.6	14.6
34.00	66.00	356.0	16.7
30.00	70.00	365.0	15.8
20.00	80.00	388.4	15.2
10.00	90.00	419.0	13.3
0.00	100.00	450.0	4.1

Newly soldered work should not be moved for a few moments, as any movements of the parts during the transition of the solder from the fluid to the solid state disturbs its crystallization and the complete union of the several parts. In hard soldering it is frequently necessary to bind the work together in their respective positions; this is done with soft iron binding wire, which for delicate jewelry work is exceedingly fine, and for stronger work is $\frac{1}{16}$ or $\frac{1}{32}$ inch in diameter.

It is passed around the work in loops, the ends of which are twisted together with pliers. In soft soldering, the binding wire is scarcely ever used, as, from the moderate and local application of the heat, the worker's hands may be freely used in retaining most of the work in position during the process.

Hard solders.—These are alloys of copper and zinc; or copper zinc, and nickel; or silver, copper, and zinc; and a good example of this class is spelter solder consisting of approximately 50% copper and 50% zinc. A typical silver solder contains 60% silver, 23% copper, and 17% zinc. The flux used with such solder is either borax or soda ash.

Brazing solder.—This is usually sold in a granulated condition, the granulating may be done by pouring from a height into water, or the alloy may be cast into ingots and broken with a hammer when re-heated. Brazing solder can also be made by granulating the alloy by stirring it briskly as it is about to congeal. Sheet or wire is sometimes desired by the trade; but in this form the solder has a higher melting point than in the form of granules, because it is not possible either to roll or to draw into wire a brass with as much as 50% of zinc, consequently the percentage of zinc is reduced, in order to get a metal that will roll or draw, with the result of raising its melting point. The 60-40 copper-zinc mixture is the one containing the largest amount of spelter that can be rolled or drawn. The favorite mixture consists of 7 parts copper and 4 parts spelter, which makes a 63.50-36.50 brass. An analysis made by Sperry on so-called spelter wire gave the following:

Spelter wire (Sperry)

	Per cent
Copper.....	63.76
Zinc.....	35.64
Lead.....	0.39
Iron.....	0.21

The melting point of this alloy is too high for brazing brass, though it can be used for iron and steel. For brass,

the granulated spelter solder can be safely used. It is conveniently made by melting sheet brass of known composition and adding zinc, for the reason that brass melts more easily than copper. Brass solder, or spelter solder, is the most fusible of all the hard solders, and is prepared in different proportions of copper and zinc; and sometimes tin is added to increase its fusibility. The following table shows the composition of various kinds of solders that have stood the practical test of years:

TABLE 80.—*Composition of hard solders*

	Copper, %	Zinc, %	Tin, %	Lead, %
Very refractory.....	57.94	42.06		
“ “.....	58.33	41.67		
Refractory.....	50.00	50.00		
Readily fusible.....	33.34	66.66		
Half-white, readily fusible.....	44.00	46.90	3.30	1.20
White.....	57.44	27.98	14.58	
Malleable solder.....	72.00	18.00	4.00	
Hard solder according to Volk....	53.30	46.70		

Since these solders are generally prepared by melting together brass and zinc, the next table gives the proportions of brass (in sheet) and zinc required for the purpose, in parts:

TABLE 81.—*Brass and zinc used in hard solders*

	Brass	Zinc	Tin
Very refractory.....	85.42	12.58	
“ “.....	7.00	1.00	
Refractory.....	3.00	1.00	
“ “.....	4.00	1.00	
Readily fusible.....	5.00	2.00	
“ “.....	5.00	4.00	
Half-white.....	12.00	5.00	1.00
“ “.....	44.00	20.00	2.00
White.....	40.00	2.00	8.00
“ “.....	22.00	2.00	4.00
“ “.....	18.00	12.00	30.00
Very ductile.....	78.25	17.25	
For girdlers.....	81.12	18.88	

Prechtl's brass solders consist of the following metals, in parts:

Mixtures for Prechtl's brass solders

	Copper	Zinc	Tin	Lead
Yellow, refractory.	53.30	43.10	1.30	0.30
Half-white, readily fusible.	44.00	49.90	3.30	1.20
White.	57.44	27.98	14.58	

The next table gives the melting points of brazing solders:

TABLE 82.—*Melting points of brazing solders*

No.	Copper, %	Zinc, %	Melting point, °F.
1	100.00	0.00	1992
2	96.00	4.00	1979
3	86.00	14.00	1902
4	80.00	20.00	1958
5	76.00	24.00	1808
6	72.00	28.00	1768
7	71.00	29.00	1758
8	66.40	33.60	1696
9	63.00	37.00	1678
10	60.00	40.00	1646
11	50.00	50.00	1628
12	48.00	52.00	1610
13	41.00	59.00	1536
14	35.00	65.00	1513
15	33.00	67.00	1489
16	29.00	71.00	1479
17	24.00	76.00	1375
18	20.00	80.00	1313

Making hard solder.—In making solders, great care should be taken to secure uniformity of composition. They are generally procurable in a granulated form or cast into ingots. The most suitable procedure for their preparation is as follows: Perfectly homogeneous sheet brass is used, it being preferable to cast brass, as by rolling it has acquired greater homogeneity. To prepare the brass for the manufacture of solders directly by melting together copper and zinc is not advisable, as the unavoidable loss of zinc during the operation can never be exactly determined; but by using finished brass

it can, however, be readily melted down and compounded, if necessary, with zinc, without any sensible volatilization of the latter.

The brass is first melted in a crucible at as strong a heat as possible, and when thoroughly fused, all of the zinc to be used, and which has previously been highly heated, is added. The contents of the crucible are then vigorously stirred, and after a few minutes are poured. The granulation of the solder is effected by pouring the molten metal from the crucible or ladle through a wet broom or from a considerable height into cold water. The size of the grains thus obtained varies within wide limits, and in order to obtain a uniform product the grains should be passed through different size sieves and all excessively large pieces re-melted.

According to another method, the molten metal is poured into a shallow vessel filled with cold water in which lies a large iron ball so as partly to project from the fluid. The metal falling upon the ball in a fine stream flies into small pieces of nearly uniform size, which fall into the water, where they quickly harden.

The finest product is, however, obtained in the following manner: At some distance above the level of the water serving for the collection of the grains, a horizontal pipe is arranged which is connected either with a powerful force pump or a water reservoir situated at a high level. Before pouring the molten metal, the cock on the pipe is opened so that the jet of water issuing therefrom is thrown in a horizontal direction over the vessel containing the water, and on this jet of water the stream of melted metal is poured. The greater the force with which the water issues from the pipe the greater the force with which the stream of molten metal is divided, and by this means it is possible, within certain limits, to obtain grains of a determined size. As will be seen from the above description, the scattering of the stream of melted metal is based on the same principle as that employed in diffusing or atomizing fragrant liquids into the atmosphere.

Casting being finished, the grains of solder deposited on the bottom of the vessel are collected and quickly dried to prevent them from being oxidized to a dull appearance.

Argentan solder.—The metallic mixture to which this term is applied not only serves for soldering articles of argentan or German silver, but on account of its refractory character and toughness, it is generally used for soldering articles where the joints are to be especially solid. It is also frequently employed for soldering fine articles of steel and iron.

As regards its composition, argentan solder is a variety of German silver rich in zinc, which must show considerable brittleness, so that it can be mechanically converted into a fine powder. Its composition varies, depending chiefly upon the composition of the articles to be soldered with it. Manufacturers of German silver articles rich in nickel, consequently more difficult to fuse, as a rule, use a somewhat more refractory solder than those manufacturing alloys which contain but little nickel, and which are more fusible.

As argentan solder is not only employed for soldering nickel silver, but also for articles of steel, efforts have been made to prepare compositions answering all demands, of which the following have stood a practical test:

(1) Readily fusible argentan solder: Copper, 35 parts; zinc, 57 parts; and nickel, 8 parts.

(2) Less fusible argentan solder, especially adapted for iron and steel: Copper, 38 parts; zinc, 50 parts; and nickel, 12 parts. The alloys are melted in the same manner as German silver and cast in thin plates, which, while still hot, are broken into pieces and converted into as fine a powder as possible in an iron mortar previously heated. If the alloy is readily comminuted, it contains too much zinc; if with difficulty, too little zinc. However, in either case it does not possess the properties of argentan solder of the proper proportions, so it should be re-melted. Hence, it is best first to ascertain by small samples whether the alloy has the correct composition. For this purpose a small quantity of the molten

metal is taken from the crucible by means of a ladle and poured on a cold stone, and then tested as to its behavior in the mortar.

Any excess of zinc can be removed by keeping the alloy in flux for some time with the crucible uncovered, whereby a considerable quantity of zinc volatilizes, and after continuing the heating for some time, an alloy showing the required zinc content is obtained. But this method is expensive, as it consumes time and fuel. It is, therefore, more suitable to throw small pieces of strongly heated German silver into the molten alloy, and effect an intimate mixture of the metals by stirring with a wooden rod. Any lack of zinc can be more readily corrected than an excess, it being only necessary to throw a small quantity of zinc into the crucible and distribute it as uniformly as possible in the molten mass. After adding the zinc, and testing once or twice, a solder answering all requirements will be obtained.

Argentan solder has a pure white color and strong luster. It melts at a fairly high temperature, and for this reason is well adapted for soldering apparatus where high temperatures are produced.

Gold and silver solders.—These solders will be found briefly discussed in Chapter XXI, under alloys of gold, silver, and platinum; but the apparatus employed may be shown here.

Watchmakers who are often called upon to repair jewelry can doubtless use the soldering pan used in Switzerland. The broken parts—for instance, the soldered joint of a ring—must be carefully joined by binding wire before the actual job of soldering is commenced. This part of the process requires skill. Then there are difficulties in hard-soldering jewelry with pearls or jewels set therein because these cannot stand the heat, but these difficulties are fairly well remedied by the pan shown in figure 104 A, B, and C. It consists of a suitable deep copper pan *s* (figure A), furnished with handle. The pan has two lateral projections, *a* and *c*, in which move two milled screws, *x* and *m*. These may be

used to good effect if a broken ring is to be soldered, as it is only necessary to fasten it between the screws *K* and *M*, with the joint to be soldered turned up, after which the job of soldering may be undertaken with little trouble.

For other purposes, the two clamps *L* and *L'* (figure B) are used besides the screws *K* and *M*, for instance, when the upper plate *F* is to be soldered on a stud. Of the two clamps, one moves in the handle of the pan; the other in an opposite shoulder *b* (figure A), moving with tight friction so that they

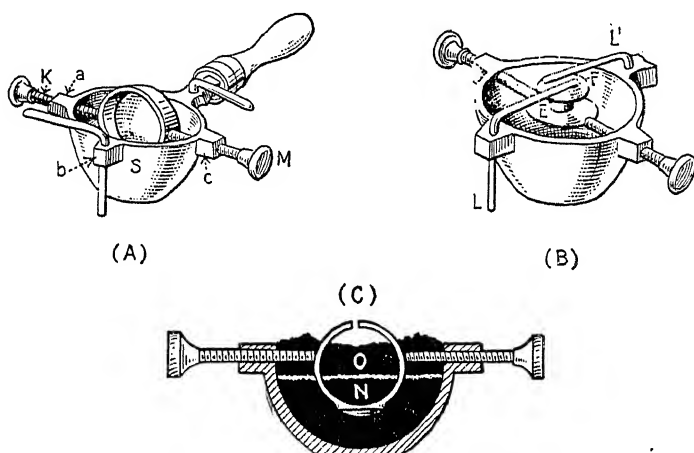


Figure 104.—Apparatus for soldering jewelry.

will keep steady the part *F* to be soldered, if previously the lower part *E* of the stud was fastened between the screws (figure B).

In figure C the pan is shown in cross-section to show how it is to be used in case a ring with jewel is to be soldered. This is to be fastened as deep as possible between the screws, and the pan is then filled to a proper height with sand. Above is placed a layer *O*, of small pieces of coal or asbestos, and soldering may then be commenced without danger to the jewel.

Aluminum solders.—Aluminum alloys at both ends of the scale—those with a base of aluminum and those with a base of copper—are very difficult to solder. The surfaces to be

soldered must be thoroughly cleaned by filing, chipping, or scraping to get down to metal. No flux is ordinarily used; the surfaces are tinned, using a blow-torch or other means of heating which will heat the aluminum to about 572° F., to melt the aluminum solder. A clean flame must be used; a soldering iron can be used only for the very smallest articles, as the conductivity for heat of the aluminum being high, the heat is absorbed from the iron before the solder melts. Using the torch, it must be directed onto the surfaces to be joined until the solder melts, then it must be rubbed in with a wire brush. The heated article must melt the solder; it cannot be melted and be dropped on like soft solder. Both surfaces to be soldered must be treated, then they are brought together using a little additional solder between. The heat of the article must be sufficient to melt the solder, and the parts must be strongly squeezed together and rigidly held in the one position until cold. In filling up cracks, the opening should be chipped out to a V-shape.

On the subject of aluminum solders, the U. S. Bureau of Standards has published Circular No. 78, from which are abstracted the following remarks, which cover the subject completely:

Aluminum solders generally consist of mixtures of tin, zinc, and aluminum, all of which combinations are electro-negative to aluminum, meaning that a soldered joint, in the presence of moisture, acts similar to an electric battery in that a current of electricity flows from the aluminum to the solder, the result being the aluminum is carried away or corroded in a manner analogous to that of an anode in a plating solution. For this reason, soldered joints on aluminum surfaces should be always protected against corrosion by paint or varnish which acts by excluding moisture from the joint. In the case of heavy objects, such as castings, this may be unnecessary unless the water is liable to work its way into the joint. Some solders are more efficient than others; a good solder should not be brittle, and ought to possess a tensile strength of about 7000 lb. per sq. in. The strength of a joint depends upon its type and the workmanship with which it was put together, and too much dependence should not be placed on it.

The operation of soldering aluminum consists in first cleaning the metal surfaces to be joined with a fine file or emery paper, after

which they are tinned or coated with a layer of the solder, accomplished by heating the joints and then rubbing the solder on until they are uniformly coated. The solder should "wet" the surfaces and unite with them, and after this has been accomplished the joint itself can be made by ordinary methods and with ordinary soft solder. Only the tinning mixture need be special with aluminum. The efficiency of the joint depends upon the degree of adhesion that is secured between the aluminum and the solder used for the initial tinning operation.

A number of tests were conducted by the Bureau of Standards, and among other things it was shown that the best adhesion of the initial tinning was secured in the case of the higher melting point solders, because, in order to get them to flow, greater heat was required, and this appeared to be an important factor in the process. A solder high in zinc or aluminum meets this condition; but on the other hand zinc-base solders are themselves attacked by corrosion, together with the aluminum, while in the case of tin-base solders only the aluminum is attacked.

The use of fluxes in connection with soldering gains no advantage, either as regards the tinning operation or the adhesion of the tinned metal surfaces; therefore, the soldering of aluminum is best accomplished without any flux. Some fluxes used are stearic acid, rosin, zinc chloride, soap, sugar, and mixtures of these substances.

An aluminum solder should consist of a tin-base alloyed with zinc or aluminum as follows: Tin, 50 to 85%, and zinc, 15 to 50%. For a higher melting-point solder, use tin, 87 to 73%; zinc, 8 to 15%; and aluminum, 5 to 12%. The percentage composition of some aluminum solders is given in the following table:

TABLE 83.—Composition of aluminum solders (Bureau of Standards)

Name	Zinc	Tin	Alu- minum	Phos- phorus	Cop- per	Phos- phor- tin	Lead	Anti- mony	Cad- mium
Burgess and Hambuechen.	21.00	76.00	3.00						
Richards.	31.00	63.00	3.00			3.00			
Auel.	35.00	63.00	0.25		2.00				
Wust.	50.00		30.00		20.00				
" No. 2.	65.00		20.00		15.00				
" No. 3.	80.00		12.00		8.00				
Bates.		30.00	70.00						
Sterling.	15.20	61.60	11.20		2.50		8.30	1.20	
Roesch.	50.20	48.60			0.20			0.70	
Crown.	18.00	63.00	13.00		3.00		1.00	2.00	
So-Luminum.	33.00	55.00	11.00		1.00				
Seifert.	21.00	73.00				1.00	5.00		
Bureau of Standards No. 1.	8.00	78.00	9.00						5.00
" " No. 3.	9.00	86.00	5.00	0.25					
" " No. 4.	9.00	86.00	5.00						
Zi.	75.00		5.00						20.00
Geophysical Laboratory, Carnegie Institute.	90.00		6.00		4.00				
	50.28		0.16				0.36		48.79
No. 2.	26.20	69.00	2.40	2.40					
Gopmans.	20.31	49.05					26.06		

* Also 0.24% iron.

Soldering aluminum bronze.—The most satisfactory way of soldering aluminum bronze is first to copper or nickel-plate it, and then solder on the plating. The parts can be coppered by first cleaning them free of dirt and grease, then putting them in a strong solution of copper sulphate, and placing a rod of soft iron in the bath in contact with the parts to be joined. After a short period the surface of the aluminum bronze will take on a copper color. The bronze should then be removed from the bath, rinsed, and dried, and the coppered surfaces can be tinned the same as copper itself. When it is desired to hide the fact that a plating operation has been done on the bronze, it can be nickel-plated and the soldering done on the nickel. It is surprising how solder will adhere to plated surfaces of aluminum bronze—steel tubing has been connected by using such castings, and as it was not possible to connect the castings and the steel tubing by any other means than electroplating and soldering to the plate, this was done, and the joint so made proved both strong and lasting.

CHAPTER XXVII

MISCELLANEOUS ALLOYS

Acid-resisting alloys.—According to R. Irmann in *Metal und Erz* (volume 14, 1921, page 37), the resistance of nickel to hot concentrated sulphuric acid is increased rapidly by alloying with copper—equal parts of the two metals producing the most non-corrodible alloy. Only nickel is dissolved by the acid. Alloys of tungsten, copper, and nickel may be prepared by adding copper to a molten mixture of nickel and tungsten. As the tungsten is increased the power of dissolving copper is reduced. Alloys that are highly resistant to sulphuric acid are those containing 2% of tungsten, 20% of copper, and 78% of nickel; also 5% of tungsten; 45% of copper, 70% of nickel and 10% of tungsten; 15% of copper and 75% of nickel. The electric resistance of the above alloys, Irmann claims, is higher than that of constantan. The alloys roll well. Iron also may be added with good results, an alloy recommended being as follows: copper, 40%; nickel, 52%; tungsten, 4%; and iron, 4%.

Other acid-resisting alloys are shown in table 84, by percentage.

Table 85 includes a miscellaneous assortment of alloys, in percentages, save where otherwise indicated.

Stainless steel.—While the stainless steels might have been included under chromium or steel, they may be placed as miscellaneous alloys. According to Dr. W. H. Hatfield* of the Brown-Firth Research Laboratories at Sheffield, England, stainless steel was discovered by Harry Brearley in 1912. He found that 12 to 14½% chromium steels, when hardened,

* Trans. Inst. of Min. Eng., England, vol. 63, part 3, May, 1922, p. 177.

TABLE 84.—Acid-resisting alloys

Name	Cr	C	Si	Fe	Mn	P	S	Ni	Pb	Cu	Mo	Al	Sn	Zn	W	Remarks
Becket U. S. patent 1,245,552 (1917).	25.0— 30.0	1.5— 3.0	3.0	Re- mainder	0.25— 0.35	0.16— 0.20	0.05									Tough and non-oxidizable casting alloy. Resists sulphuric acid; sp. gr., 7.0; melting point, 2500 to 2550° F.; compression strength 70,000 lb. per sq. in. = about 25% less than cast iron.
Duriron.....		0.20— 0.60	14.00— 14.50	Re- mainder												Sp. gr., 6.8; melting point, 2550° F.; max. pressure of a tantiron autoclave, 40 to 50 lb. per sq. in. Claimed to resist action of 25% nitric acid for 24 hours without weighable loss.
Tantiron.....		0.75— 1.25	14.00— 15.00		2.00— 2.50	0.05— 0.10	0.05— 0.15									Bronze used in acid mine waters. Bronze used for pump bodies and exposed parts. Alloy should be homogenous, and should be made with a hardener after copper has been added to prevent oxidation.
.....	21.10		1.00	0.80	1.00			61.50		6.50	4.75	1.10			2.25	
.....						0.10		3.00	15.00	84.00			3.00			
.....									15.00	75.00			9.90			
Ilflum.....	21.00			1.00	1.00			52.00		6.50	5.00	1.00			2.00	Melting point, 2372° F. Used for condenser tubes.
Nergandin.....				2.00	5.50*			55.50	2.00	70.00		0.25			28.00	Non-corrodible in salt solutions.
.....								50.50	4.55	86.07			9.19	0.14		Resists hot concentrated sulphuric acid.
.....				1.87						43.65					3.90	Resists hot concentrated sulphuric acid.
Arch's metals.....				1.80						60.00						Used for marine castings.
Aluminum bronze.....				4.00						87.50		8.50				A strong alloy; 2 bars gave tensile strength of 78,000 and 80,000 lb. per sq. in.; and each an elongation of 40%.
Anaconda bronze.....										90.00						For mine pumps.
Acid bronze.....								1.50	17.00	73.50			10.00†			

* Manganese copper.

† Phosphor tin.

resisted the general atmospheric and many other active corroding influences. These steels are rust-resisting and stain-resisting alloys. The carbon, manganese, silicon, and other elements are controlled within desirable limits. The alloy is made by the electric process of steel manufacture, and then simply machined to shape. Its mechanical properties are high when compared with ordinary carbon steels. In the article mentioned, a table shows the results of 200 tests made with 68 different acids, gases, etc., whose effect in general was little or nothing.

In the United States we have a stainless alloy termed "stellite," one consisting of 75% cobalt and 25% chromium, invented by Elwood Haynes of Kokomo, Indiana.† It is used for lathe tools, surgical knives, and cutlery; and is stainless. Many tests made at Perdue University showed little or no effect when treated with 20% nitric acid, 25% sulphuric acid, 23% hydrochloric acid, 38% hydrofluoric acid, 10% acetic acid, aqua regia, 5% carbolic acid, 90% phosphoric acid, 10% caustic soda, 5% mercuric chloride, iodine tincture, formaldehyde, 5% potassium permanganate, 10% silver nitrate, 10% copper sulphate, 5% oxalic acid, and sodium hypochlorite.

Several other alloys requiring more or less lengthy description follow:

Igniter pin alloys.—The igniter pins used in miner's safety-lamps are largely composed of cerium, as the following table shows for four different alloys:

Composition of igniter pin alloys

Cerium.....	73.0	61.2	70.1	72.1
Iron.....	1.6	37.3	6.2	6.2
Zinc.....	24.2	.....	19.7	17.5
Aluminum.....	.....	.....	2.4	..
Manganese.....	.....	.....	.....	0.1
Oxygen and impurities.....	1.2	1.4	1.6	4.1

† Mineral Resources of United States, 1918, U. S. Geological Survey.

TABLE 85.—

Name	Cr	C	Bi	Si	Fe	Mn	P	Co	Ni
Air-pressure alloy.....									
No. 2 air-pressure alloy.....									
Air-pressure alloy (high).....									
Allen's metal.....					1.00—				67.00
Alloy of same coeff. of expansion as iron.....		None			5.00				
Balance springs.....	10.00— 12.00			1.00— 2.00	44.00— 53.00	1.00— 2.00			33.00— 39.00
Bell metal.....									82
Bending alloy.....									
Benedict nickel.....									20.0
Black bronze.....									
Booster metal.....									
Brazing metal.....									
Bronze dies.....									
Builder's hardware (best).....									
Builder's hardware (seconds).....									
Calorite.....	12.00				15.00 2	8.00			65.00
Chain bronze.....									
Chromax.....	3.03								15.15
(French).....	2.75								13.75
Church bells.....						1a	2b		
Condenser sea valves.....									
Cooperite.....									80.00
Collector rings.....									
Delta metal.....					1	1a	1 oz. c		
Delta.....					3 oz.	8a			
Duke's alloy.....					30				20
Die-casting alloy.....									
Electric resistance alloys:									
Constantin.....		0.130		0.109	0.276	0.582		0.026	46.05
Manganin.....					0.30	13.60			2.50
Nichrome (cold drawn).....	12.00				25.00				60.00
(cast).....	12.00	0.60		0.40	26.00	1.00			60.00
Nichrome II.....									
Mangaloy.....					Yes	Yes			High
No. 193 alloy.....	Low								30.00g

a Manganese copper. b Phosphor-tin. c Phosphor copper. d 15% phosphor copper.

Miscellaneous alloys

Pb	Cu	Mo	Al	Sn	Zn	W	Sb	Zr	Remarks
8.50	72.50	.....	.....	1.75	19.25	.....	.....	.....	Used for cocks, bushings, pistons, etc.
5.75	82.00	.....	.....	7.50	4.75	.....	.....	.....
1.50	83.00	.....	.....	11.50	4.00	.....	.....	.....
44.61	55.25	.....	.....	0.14	.....	.....	.....	.....	Flux with galena (lead sulphide) Used for valves of internal combustion engines.
.....	28.00	.....	.....	.....	.....	.....	.....	.....	Compensating springs.
.....	32.00	.....	.....	.....	.....	1.00— 2.00	.....	.....
.....	.....	.....	1	17	.....	.....	.....	.....	In pounds. Silver color.
.....	78.00	.....	.....	22.00	.....	.....	.....	.....
1.00	92.00	.....	.....	5.00	2.00	.....	.....	.....
.....	80.00	.....	.....	.....	.....	.....	.....	.....	Can be used where a white alloy is required, also for plumber's nickeled tubing.
10	83	.....	.....	5	2	.....	.....	.....	In parts.
50.00	.....	.....	.....	40.00	.....	.....	10.00	.....	Used in cutlery industry.
1½	126	.....	.....	.....	18	.....	.....	.....	In pounds.
.....	85	.....	2 oz.	14½	.....	.....	.....	.....	"
4 oz.	10	.....	.....	15 oz.	4 oz.	.....	.....	.....	"
5 oz.	10	.....	.....	5 oz.	1¼ oz.	.....	.....	.....	"
.....	
.....	91	.....	.....	5	2	.....	.....	.....	In pounds.
.....	66.66	3.03	3.03	.....	12.13	.....	.....	.....
.....	65.50	.....	2.75	.....	11.00	.....	.....	.....	Used where a strong bronze is required.
.....	78	.....	.....	22	.....	.....	.....	.....	Denver cathedral. In pounds.
.....	86.00	.....	.....	12.00	2.00	.....	.....	.....	Torpedo boats, 16-inch valves.
.....	88.00	.....	.....	10.00	2.00	.....	.....	.....	14
.....	.....	.....	.....	.....	.....	14.00	.....	6.00	Used for cutting tools.
½	96.75	.....	.....	2	12	.....	.....	.....	In pounds.
.....	54½	.....	.....	.....	43	.....	.....	.....	"
3 oz.	10½	.....	1 oz.	1 oz.	8½	.....	.....	.....	"
.....	30	.....	.....	2	.....	.....	.....	.....	"
.....	3	.....	2	30	85	.....	.....	.....	"
.....	52.88	.....	.....	.....	.....	.....	.....	.....	Mean of 26 analyses by F. E. Bach, Trans. A. I. M. & M. E., vol. 64, p. 259.
.....	83.60	.....	.....	.....	.....	.....	.....	.....	Alloy of best coefficient according to M. A. Hart, professor in Rensselaer Polytechnic Institute.
.....	.....	.....	.....	.....	.....	.....	.....	.....	As given by L. O. Hart of Driver-Harris Co. The cast metal was developed primarily to take the place of cast-iron and steel containers for metal parts which had to be heat-treated. Does not scale or warp. Sp. gr., 8.15; weight per cubic inch, 0.29 lb.; melting point, 2660° F.; Brinell hardness, 165-175; sp. heat, 0.111 at 100° C.; thermal conductivity, 20.5% that of cast iron.
.....	.....	.....	.....	.....	.....	.....	.....	.....	Contains less iron and more chromium than nichrome. It can be used for temperatures up to 1090° C., a little above that of copper. Ordinary nichrome is used in heating appliances up to 982° C. Its electrical resistivity is 660 ohms per cir. mil-fad at 23° C.
.....	.....	.....	.....	.....	.....	.....	.....	.....	A cheap heating alloy for temperatures up to 537° C., suitable for open room-heaters.

e Brass. f Silicon copper. g Nickel steel.

TABLE 85.—

Name	Cr	C	Bi	Si	Fe	Mn	P	Co	Ni
Electric resist.— <i>Cont'd</i>									
Kromore.....	15.00								85.00
Climax.....	None								25.00
Elephant S. B. and phosphor bronze.....							0.59		
Engravers' plates.....							2 oz. <i>c</i>		
Expands on cooling.....			2	1					
Ferrules.....									
Gas cocks.....									
Gear bronze.....									
Gilding metal.....									
Hard phosphor bronze.....							7 <i>d</i>		
Inbar.....					64.00				36.00
Key alloy.....					0.41				12.67
Key metal.....									
Lutecine or Paris metal.....					5			5	160
Marlie's non-oxidiz- able alloy.....					10				35
Magnolia metal.....									
Mechanical copper castings.....									
Mine pump chambers.....							4 oz. <i>c</i>		
Motor bearings.....									
Name-plates.....									
Nickel valve-seats.....				2 <i>b</i>					48
Ounce metal.....									
Optical bronze.....					4		5 oz. <i>a</i>		
Pattern bronze.....									
Plastic bronze.....									1.00
Refrigerator hardware.....									
Robertson alloy.....									
Rose copper.....				1 <i>f</i>					
Saddlery hardware.....									
Steam metal.....									
Steam metal (plumb- ers).....									
Samrit bronze.....									
Stone bronze.....					1.50	0.50			
Sterro metal (1).....					4.66				
(2).....					1.50				
Tissier's metal.....									
Violet-colored alloy.....									
Water-resistant alloys (1).....									
Water-resistant alloys (2).....									
Water-resistant alloys (3).....									
White brass.....									

a Manganese copper. *b* Phosphor-tin. *c* Phosphor copper. *d* 15% phosphor copper

Miscellaneous alloys—Continued

Pb	Cu	Mo	Al	Sn	Zn	W	Sb	Zr	Remarks
.....	.....	.....	.....	.....	.....	.....	.....	.....	Used for "extreme" temperatures and open-type heating units (electrical) specific resistance of 577 ohms per mil-fad at 20° C.
9.05	80.00	.....	.....	10.36	.....	.....	.....	.....	A cheap resistance material.
.....	95.00	.....	.....	.....	6.00	.....	.....	.....	Sperry.
9	.....	.....	.....	.....	.....	.....	2	.....	In parts. Suitable for filling up small holes and defects in cast-iron.
6	52	.....	6 oz.	.....	41 $\frac{3}{4}$	.....	.....	.....	In pounds. Plumbers' mixture.
6 oz.	10	.....	.....	5 oz.	4 $\frac{1}{2}$	.....	.....	.....	In pounds.
3.00	66.00	.....	.....	.....	31.00	.....	.....	.....	Tensile strength, 36,000 lb. per sq. in.; elongation in 2 inches, 2% or less.
.....	85.00	.....	.....	13.00	2.00	.....	.....	.....	In pounds.
.....	90	.....	.....	.....	10	.....	.....	.....	.....
7 $\frac{1}{2}$	73 $\frac{1}{2}$	.....	.....	12	.....	.....	.....	.....	.....
1.10	65.16	.....	.....	0.15	20.15	.....	.....	.....	.....
1 oz.	16	.....	.....	2 oz.	1 oz.	.....	.....	.....	In parts.
.....	800	.....	.....	20	5	.....	.....	.....	Articles are heated to white heat and dipped in a mixture of 60 parts sulphuric, 10 parts nitric, and 5 parts hydrochloric acids, and 25 parts of water.
.....	25e	.....	.....	20	10	.....	.....	.....	.....
80.00	.....	.....	.....	5.00	.....	.....	15.00	.....	In pounds.
.....	16	.....	.....	1 oz.	2 oz.	.....	.....	.....	.....
3	100	.....	.....	17	.....	.....	.....	.....	.....
20	74	.....	.....	6	2 $\frac{1}{2}$	.....	.....	.....	.....
1 $\frac{1}{2}$	90	.....	.....	.....	.....	.....	.....	.....	.....
.....	50	.....	.....	.....	.....	.....	.....	.....	.....
5	85	.....	.....	5	5	.....	.....	.....	.....
.....	90	.....	.....	5 $\frac{1}{2}$	2	.....	.....	.....	.....
.....	93	.....	.....	7	.....	.....	.....	.....	.....
1.50	90.00	.....	.....	6.00	2.50	.....	.....	.....	.....
30.00	64.00	.....	.....	5.00	.....	.....	.....	.....	.....
8 oz.	10	.....	1 oz.	.....	5 $\frac{1}{2}$	.....	.....	.....	In pounds.
.....	.....	.....	.....	.....	.....	.....	.....	.....	1 part gold, 3 parts silver, 2 parts tin. Melt the first two, and add tin at moment of fusion. When cold, the alloy may be pulverized. Equal quantities of alloy and mercury are kneaded on palm of hand to form paste for filling teeth.
.....	100	.....	.....	2	.....	.....	.....	.....	In pounds.
9 oz.	10	.....	1 oz.	.....	7 $\frac{1}{2}$	.....	.....	.....	.....
3.00	87.00	.....	.....	7.00	3.00	.....	.....	.....	.....
1.50	87.00	.....	.....	4.50	7.25	.....	.....	.....	.....
.....	85.11	.....	.....	12.76	.....	.....	.....	.....	Also 2.13% mercury. Tin is melted first, and mercury mixed therewith forms an amalgam. Copper is melted under charcoal, and tin is added in very small pieces to avoid explosion. Used in Siam for casting statues.
.....	58.00	.....	0.75	0.25	39.00	.....	.....	.....	A strong alloy similar to manganese bronze.
.....	55.33	.....	.....	.....	41.80	.....	.....	.....	.....
.....	60.00	.....	.....	.....	38.12	.....	.....	.....	Also 1% arsenic.
.....	97.00	.....	.....	.....	2.00	.....	.....	.....	In parts. A beautiful violet.
.....	50	.....	.....	.....	.....	.....	50	.....	For filters, bolts and other castings for city water-works.
0.50	60.75	.....	.....	0.75	38.00	.....	.....	.....	For strainer plates for city water-works.
0.25	66.50	.....	.....	0.25	33.00	.....	.....	.....	For valves, etc., for city water-works.
2.00	86.00	.....	.....	7.00	5.00	.....	.....	.....	In pounds.
.....	.....	.....	.....	60	38	.....	2	.....	.....

e Brass. f Silicon copper. g Nickel steel.

When this pin rubs a prepared tape or hard steel friction wheel, sparks are emitted, which light an oil wick in the lamp.

Sideraphite.—The alloy known under this name resembles silver, and is very ductile and malleable. It is composed of 63 parts iron, 23 of nickel, 4 of tungsten, 5 of aluminum, and 5 of copper. The iron and tungsten are melted together, and then granulated by being thrown into water. The water used for this purpose should contain 1 lb. of slaked lime and 1 lb. of potash for every gallon. The nickel, copper, and aluminum are also melted together, and the product thus obtained is also granulated in water containing the same proportion of lime and potash. During melting, the metals in the two crucibles must be kept covered with a flux made of 2 parts each of borax and niter. A piece of soda or alkali, weighing about the $\frac{1}{2500}$ part of the whole mass, is put in the crucible containing the copper, nickel, and aluminum to prevent oxidation of the last-named metal; and to prevent the same action taking place with the copper, a small piece of charcoal is added. Previous to the operation of granulation the contents of the two crucibles should be well stirred. The granulated metals are dried, melted in the proportions given above, well mixed, and then run into bars. This alloy is claimed not to be more expensive than ordinary white metal. It will resist the action of sulphuric acid, is not attacked by organic acids, and but slightly so by the inorganic acids.

Silvering alloy.—This alloy consists of 80 parts tin, 18 of lead, 2 of silver; or 90 parts of tin, 9 of lead, and 1 of silver. Melt the tin, and when the bath is lustrous white, add the granulated lead and stir the mixture with a pine stick; then add the silver and stir again. Increase the heat for a short time until the surface of the bath assumes a light yellow color, then stir thoroughly and cast the alloy into bars. The operation of silvering is executed as follows:

The article, a knife-blade, for instance, is dipped in a solution of hydrochloric or sulphuric acid, rinsed in clean water, dried, rubbed with a piece of soft leather or dry sponge, and then exposed in a muffle 5 minutes to a temperature of

158 to 176° F. The effect of this treatment is to render porous the surface of the iron or steel. With poor and coarsely porous iron the silvering process is difficult; with steel, however, the process is easy. The article heated to about 140° F. is dipped into the alloy melted in a crucible over a moderate fire. The bath, which must be completely liquid, is stirred with a pine or poplar stick. The surface of the bath should show a fine silver-white color. One or two minutes dipping suffices for a knife-blade. When taken from the bath the article is dipped into cold water; or, if necessary, hardened and tempered in the usual manner. It is then rubbed dry and polished without heating.

Articles thus treated have the appearance of silver, and also possess the sound of silver, and resist oxidation in the air. To protect them from the action of acid liquors they are first dipped in an amalgam bath of 69 parts of mercury, 39 parts of tin, and 1 part of silver; then, while hot, in melted silver, and electroplated with silver. This method of silvering is claimed to be very durable and not costly.

Spence's metal.—This compound is a British invention, and is named after the inventor. Strictly speaking, it is not a metal, but a compound obtained by dissolving metallic sulphides in molten sulphur, which is found to be capable of receiving into solution nearly all the sulphides of the metals. For most purposes the inventor employed in the production of his "metal" the sulphides of iron, lead, and zinc, in varying proportions, according to the quality of the product desired, which will depend on the uses for which it is designed. The mixture solidifies on cooling, forming a homogenous, tenacious mass, having ordinarily a specific gravity of 3.37 to 3.7. It is said to be exceedingly useful in the laboratory for making the air-tight connections between glass tubes by means of rubber and a water or mercury jacket where rigidity is no advantage. The fusing point is so low that it may be run into the outer tube on to the rubber, which it grips, on cooling, like a vise and makes it perfectly tight. It melts at 320° F., expands on cooling, is claimed to be

TABLE 86.—*Properties of various metals and alloys (Woodward)*

Material	Tensile strength, lb. per sq. in.	Elongation, in 2 in., per cent	Modulus of elasticity, lb. per sq. in.	Compressive strength, lb. per sq. in.	Brinell hardness number	Density, lb. per cu. ft.	Melting point, ° F.	Coefficient of linear expansion per ° F.	Resistance, ohms per circular mil-ft.	Temp. coefficient of resistance per ° F.
Cast iron.....	30,000	None	15,000,000	100,000	100	450	2000	0.0000068		
Wrought iron.....	50,000	35	25,000,000	30,000	125	480	2760	0.0000066	60	0.00322
Low-carbon steel, annealed.....	60,000	35	30,000,000	40,000	.....	490	.....	.....	95	0.00183
Low-carbon steel, cold-rolled.....	50,000	20	30,000,000	60,000	.....	490	.....	.....
Medium-carbon steel, annealed.....	80,000	28	30,000,000	50,000	135	490	About	About		
Medium-carbon steel, heat-treated.....	125,000	13	30,000,000	100,000	300	490	2500	0.0000067		
High-carbon steel, annealed.....	86,000	33	30,000,000	.....	156	490				
High-carbon steel, heat-treated.....	200,000	10	30,000,000	.....	375	490				
Alloy steel, heat-treated.....	225,000	10	30,000,000	200,000	410	490				
Copper.....	35,000	50	17,000,000	.....	42	555	1981	0.0000095	10.37	0.00220
Cast red brass.....	30,000	22	13,000,000	30,000	40	535	.....	0.0000105	39.5	0.00055
Cast gun-metal or government bronze.....	38,000	25	13,000,000	.....	64	545				
Manganese bronze, rolled.....	75,000	25	16,000,000	.....	100	545				
Zinc.....	12,000	..	11,000,000	25,000	48	445	786	0.0000163	36.5	0.00210
Aluminum.....	13,000	25	10,000,000	67,000	25	165	1218	0.0000130	16.98	0.00216
No. 12 aluminum cast alloy.....	20,000	3	10,000,000	.....	55	176				
Duralumin, rolled and heat-treated.....	55,000	25	10,000,000	.....	.....	175	1200	.....	28.3	
Tin.....	4,000	35	4,000,000	6,400	14	455	450	0.0000136	67.9	0.00240
Lead.....	2,000	..	700,000	.....	.....	710	621	0.0000164	125.0	0.00217
Genuine babbit.....	.....	..	.....	15,000	25	460	460	.....	
Platinum.....	35,000	50	23,000,000	.....	.....	1340	3191	0.0000050	66.0	0.00204
Gold.....	30,000	25	.....	.....	.....	1200	1945	0.0000081	14.5	0.00206
Silver.....	45,000	..	9,000,000	.....	.....	650	1765	0.0000108	9.9	0.00222
Nickel.....	40,000	10	29,000,000	.....	76	570	2646	0.0000071	64.0	0.00230
Nichrome.....	150,000	..	.....	.....	.....	517	2860	0.0000091	657.0	0.00024
Manganin.....	.....	..	.....	.....	.....	.....	.....	.....	260.0	0.000006
Constantan.....	120,000	..	.....	.....	.....	554	2300	0.0000080	293.0	0.000001

capable of resisting well the disintegrating action of the atmosphere, is attacked by but few acids and by them but slowly, or by alkalies; is insoluble in water and may receive a high polish. It makes clean, full castings, taking very perfect impressions; it is cheap and easily worked. It has been used as a solder for gas-pipes, and as a jointing material in place of lead.

Tempered lead.—This consists of 98.51% lead, 0.11% antimony, 0.08% tin, and 1.3% sodium. It is manufactured by placing small fragments of sodium in the molten metal. This alloy is not as soft as lead, and can be rolled into thin sheets without tearing. When the proportion of sodium is rather large, tarnishing is prevented by coating the metal with paraffin. Thus formation of soda is prevented, owing to oxidation of the excess of sodium by atmospheric oxygen. For this reason it is useful for the manufacture of shaft bearings, because the soda formed, as the bearings wear away, saponifies the lubricant and produces a soap which acts even better than the oil.

In table 86 are given the properties of various metals and alloys compiled by R. W. Woodward of the Metallurgy Division of the U. S. Bureau of Standards. The values are typical, but should not be used for design purposes of precise significance, especially if details of the special alloy in question are available. They form, however, a convenient reference table for data not commonly summarized, and are suitable for nearly all estimates.

CHAPTER XXVIII

SURFACE COLORING OF ALLOYS

ALLOYS are frequently coated on the surface, the object being either to protect them from oxidation and discoloration or to increase their beauty. Articles of ordinary alloys, which are not to be exposed to high temperatures, are frequently only provided with a coating of lacquer usually consisting of a solution of shellac in alcohol. The lacquer may be colored by any permanent transparent alcoholic solution giving the desired tint. Dragon's blood (a gum), red sanders, or annatto is generally used for red; and gamboge, sandarac, saffron turmeric, or aloes for yellow; these coloring matters may be replaced by aniline colors. In applying the lacquer, care should be taken to keep the article to be lacquered warm and of uniform temperature, and to perform the work as quickly and smoothly as possible. Keep the lacquers in well-stoppered bottles—best of opaque material—and when using, pour them into dishes of convenient size, and apply with a thin, wide, flat brush. Table 87 is Graham's* table of lacquers.

By coating articles of copper or brass with good fat copal lacquer, and heating after drying until the lacquer commences to smoke, a coating is obtained which protects the articles as well as the tinning against the action of acid liquors.

Articles of copper and bronze exposed for a long time to the action of the air acquire a beautiful brown or green color, which considerably contributes to their appearance. This color is known as *Acerugo nobilis* (noble rust) or *patina*.

* Brass-Founder's Manual, London, 1887.

Surface Coloring of Alloys

TABLE 87.—Lacquer mixtures

Num- ber	Shellac	Mastic	Canada balsam	Spirits of wine	Pyro- acetic ether	Spirits of turpen- tine	Turpen- tine varnish	Simple pale lacquer	Drag- on's blood	An- notto	Sand- ers	Tur- meric	Gam- boge	Saf- fron	Cape aloes	Sanda- rac	Remarks
1	oz.	dr.*	dr.	pt.	oz.	dr.	oz.	pt.	dr.	dr.	gr.	dr.	cr.	cr.	dr.	dr.	Strong simple.
2	4	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Simple pale.
3	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Fine pale.
4	1	.....	.....	3	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	"
5	1	.....	.....	2	.....	.....	.....	.....	1	1	.....	.....	.....	.....	.....	.....	"
6	2	.....	.....	2	.....	.....	.....	.....	8	8	.....	.....	.....	.....	.....	.....	Plate gold.
7	2	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Pale yellow.
8	5	.....	.....	3	30	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Full yellow.
9	.....	.....	.....	.....	.....	.....	.....	1	.....	1	.....	.....	.....	.....	.....	.....	Gold.
10	3	.....	.....	1	.....	.....	.....	.....	.....	2	.....	.....	.....	.....	.....	.....	"
11	3	.....	.....	4	.....	.....	6	.....	.....	.....	.....	.....	.....	.....	.....	.....	"
12	1	.....	.....	1	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	"
13	3	.....	.....	1	.....	.....	.....	.....	4	.....	.....	.....	.....	.....	.....	.....	Deep gold.
14	3	.....	.....	1	.....	.....	.....	.....	4	.....	.....	.....	.....	.....	.....	.....	"
15	3	.....	.....	1	.....	.....	.....	.....	40	.....	.....	.....	.....	.....	.....	.....	"
16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	Red.
17	1	.....	.....	.....	.....	.....	.....	.....	8	32	.....	.....	.....	.....	.....	.....	"
18	15	.....	.....	.....	.....	.....	.....	.....	8	24	.....	.....	.....	.....	.....	.....	Tin lacquer.
19	.....	.....	.....	6	.....	.....	.....	.....	20	.....	.....	.....	.....	.....	.....	.....	Green, for bronze.

* 16 drams = 1 ounce.

Genuine patina.—Though there are many reagents by means of which a layer of patina can be produced on bronze, the coating thus obtained cannot compare, as regards beauty and durability, with the genuine patina. To obtain a coating similar to genuine patina on objects of copper, bronze, and brass, they are repeatedly brushed with solution of sal-ammoniac (ammonium chloride) in vinegar. The efficacy of the solution is accelerated by the addition of verdigris (copper acetate). A still better effect is produced by a solution of $\frac{1}{2}$ oz. of sal-ammoniac and $\frac{1}{7}$ oz. of potassium binoxalate (salt of sorrel) in 1 quart of vinegar. When the first coating is dry, wash the article and repeat the procedure, drying and washing after each application, until a green patina is formed. It is best to place the articles after being brushed with the solution into a hermetically closed box, upon the bottom of which are placed a few shallow dishes containing very dilute sulphuric or acetic acid, and a few pieces of marble. Carbon dioxide being thereby evolved, and the air in the box being kept sufficiently moist by the evaporation of water, the natural conditions under which genuine patina is formed are produced. If the patina is to show a more bluish tone, brush the objects with a solution of $4\frac{1}{2}$ oz. of ammonium carbonate and $1\frac{1}{2}$ oz. sal-ammoniac in 1 quart of water, to which a small quantity of gum tragacanth may be added.

Pale red.—All shades from the pale red of copper to a dark chestnut brown may be produced from copper by surficial oxidation. For small articles it suffices to heat them uniformly over an alcohol flame, but with large objects a more uniform result is obtained by heating them in oxidizing fluids or brushing them over with an oxidizing paste, the best results being obtained by the application of a paste prepared, according to the darker or lighter shades desired, from 2 parts ferric oxide and 1 part graphite, or 1 part of each, with alcohol or water. Apply the paste as uniformly as possible with a brush, and place the objects in a warm place—oven or drying chamber. The darker the color is to be the higher

the temperature must be and the longer it must act upon the articles. When sufficiently heated, the dry powder is removed by brushing with a soft brush, and the treatment is repeated if the object does not show a sufficiently dark tone. Finally, the object is rubbed with a soft linen rag moistened with alcohol, or brushed with a soft brush and a few drops of alcohol until completely dry, and then with a brush previously rubbed on pure wax. The more or less dark shade produced in this manner is very warm and resists the action of the air.

Brown color on copper.—Apply to the thoroughly cleansed surface a paste of 3 parts copper acetate, 3 parts ferric oxide, 1 part sal-ammoniac, and sufficient vinegar, and heat until the mixture turns black. The object is then washed and dried. By the addition of some copper sulphate the color may be darkened to chestnut brown.

A brown layer of cuprous oxide on copper articles is produced as follows: After polishing with pumice powder, brush on a paste of 4 parts copper acetate, 4 parts ferric oxide, 1 part finely rasped horn shavings, and a small quantity of vinegar. Dry, heat over a coal fire, wash, and smooth with the polishing stone.

A brown color is also obtained by brushing to dryness with a hot solution of 1 part potassium nitrate, 1 part common salt, 2 parts ammonium chloride, and 1 part liquid ammonia in 95 of vinegar. A warmer tone is produced by powdering and mixing equal parts of copper acetate and sal-ammoniac. Take a heaping tablespoonful of this mixture and boil it with water in a copper kettle for about 20 minutes, and then pour off the clear fluid. To give copper objects a bronze-like color with this fluid, pour part of it into a copper pan, place the objects separately in it on pieces of wood or glass so that they do not touch one another, or come in contact with the copper pan, and then boil them in the liquid for 15 minutes. Next, take the objects from the solution, rub them dry with a linen cloth, and brush them with a waxed brush.

A red-brown color on copper is produced in China by applying a paste of 2 parts of copper acetate, 2 parts of cinnabar, (vermilion or mercury sulphide) 5 parts of sal-ammoniac, and 5 parts of alum, with sufficient vinegar, heating over a coal fire, washing, and repeating the process.

According to Manduit, copper and coppered articles may be bronzed by brushing with a mixture of 20 parts of castor oil, 80 parts of alcohol, 40 parts of soft soap, and 40 parts of water. This mixture produces tones from bronze Barbédienne to antique green patina, according to the duration of the action. After 24 hours the article treated shows a beautiful bronze, but when the mixture is allowed to act for a greater length of time the tone is changed, and several different shades of great beauty are obtained. After rinsing, dry in hot sawdust, and lacquer with colorless spirit lacquer.

Copper is colored blue-black by dipping the object in a hot solution of $\frac{11}{16}$ ounce of potassium sulphide in a quart of water, moving it constantly. Blue-gray shades are obtained with more dilute solutions. It is difficult to give definite directions as to the length of time the solution should be allowed to act, since this depends on its temperature and concentration.

The so-called "cuivre fumé" is produced by coloring the copper or coppered objects blue-black with solution of potassium sulphide, then rinsing, and finally scratch-brushing them, whereby the shade becomes somewhat lighter. From raised portions which are not to be dark, but are to show the color of copper, the coloration is removed by polishing on a felt wheel.

A black color on copper is produced by a heated pickle of 2 parts of arsenious acid, 4 parts of concentrated muriatic (hydrochloric) acid, 1 part of sulphuric acid of 66° Bé., and 24 parts of water.

Matt-black on copper.—Brush the object over with a solution of 1 part platinum chloride in 5 parts of water, or dip it in the solution. A similar result is obtained by dipping the object in a solution of copper nitrate, or manganese nitrate,

and drying over a coal fire. This treatment should be repeated until a uniform matt-black is formed.

The bronze on French bronze figures shows all shades of pale or clay yellow to red-brown, and of red to dark and black-brown. It has a bronze-like appearance and adheres firmly to the metal—that is, appears to be chemically combined with it. To produce such colorations, solutions of sulphur, combinations of arsenic and antimony have been successfully used. After chasing and pickling, the article must be subjected to a thorough washing with water, otherwise every trace of acid left behind will later on in drying or bronzing penetrate through the seams and produce indelible stripes and stains. The drying of the article must also be done with the greatest care. For applying the solutions, some cotton lint or a soft, close brush is used. The work is best commenced by first applying a dilute solution of ammonium sulphide as sparingly as possible, brushing over a certain limited portion of the figure at one time. The quicker and more uniformly this is done the better and more beautiful the bronzing will be. After drying, the sulphur separated out is brushed off, and a solution of arsenic sulphide in ammonia applied, the result being a coloration similar to massive gold. The oftener this solution of arsenic sulphide is applied the browner the color becomes; and a very dark brown can be finally obtained by a solution of arsenic sulphide in ammonium bisulphide. With solutions of antimony sulphide in ammonia or ammonium sulphide the coloration becomes reddish, it being possible to produce the most delicate rose color as well as the deepest dark red. By rubbing certain portions somewhat more strongly, a very fine metallic luster is produced. Ammonia or ammonium sulphide re-dissolves the bronzing, so that places not thoroughly colored can be improved, though in such case it is better to rub off the entire figure with ammonium sulphide. In the same manner as the solutions in ammonia or ammonium sulphide, those in potassium hydrate or sulphide or sodium hydrate or sulphide may also be used, the latter being in some cases even more

advantageous. By pickling the figure, the color of the bronze is changed. If a casting of bronze or brass is left too long in the pickle, the metal becomes coated with a greenish-gray film, which, on rubbing with a cloth, becomes lustrous and adheres firmly. On treatment with the above metallic sulphides this coating acquires a dull-yellow coloration.

*Graham's bronzing liquors.**—These have a great range of composition and of application as given in table 88.

In the preparation of No. 5, the liquor must be brought to boiling and cooled. In using No. 13 the heat of the liquor must not be under 180° F. No. 6 is slow in action, sometimes taking an hour to give good results. The action of the others is usually immediate.

To provide articles of brass or bronze with a very lustrous gray or black coating, the tendency of certain metallic salts of forming gray or black combinations with sulphur is utilized. For gray, dip the article first into a very dilute solution of lead acetate, or for black into a solution of copper sulphate, and after drying dip into a hot dilute solution of sodium hyposulphite.

Iridescent colors.—By using very dilute solutions, the articles acquire a peculiar, iridescent appearance similar to soap bubbles. It is well known that many bodies show, when in very thin layers, the peculiar color phenomenon termed iridescence, and this is also produced by a very thin layer of lead sulphide or copper sulphide. By repeating the treatment of the article in very dilute solutions, the iridescence passes into a red, brownish, or violet coloration. It is impossible to give exact proportions for the production of these colors, the success of the coloration depending largely upon the skill of the operator.

Beautiful but not very permanent iridescent coatings may be produced by placing the bright metal in a bath of a heavy metal acted on by an electric current, touching it for a moment with the negative pole of the battery, taking it out, rinsing off, and drying. The metal will show all the colors of the

* Brass-Founder's Manual, London, 1887.

TABLE 88.—(1) *Bronzing liquors for brass by simple immersion*

Num- ber	Water	Iron nitrate	Iron per- chloride	Iron chloride	Copper nitrate	Arsenic sul- phide	Arsenic chloride	Potas- sium sul- phide	Potas- sium car- bonate	Potas- sium ferro- cyanide	Potas- sium cyanide	Sodium hypo- sulphite	Nitric acid	Oxalic acid	Result
1	pt. 1	dr. 5		pt.	oz.	gr.	oz.	dr.	dr.	pt.	oz.	dr.	dr.	oz.	Brown and every shade to black. do.
2	1		5												
3	1	16										16			Brown and every shade to red. do.
4	1											16	1		Brownish-red
5	1				1					1			3		"
6											1		4		Dark brown.
7	1														Yellow to red.
8	1					30			6						Orange.
9	1														Olive-green.
10	2			1											Slate.
11	1		5									2			Blue.
12	1														Steel-gray.
13	1						1					20			Black.
14	1			2			10								

(2) *Bronzing liquors for copper by simple immersion*

Number	Water	Iron nitrate	Copper sulphate	Antimony sulphide	Sulphur	Arsenic chloride	Potassium carbonate	Potassium sulphocyanide	Sodium hyposulphite	Hydrochloric acid	Result
15	pt. 1	dr. 5	oz.	dr.	dr.	dr.	oz.	dr.	oz.	dr.	Brown, and every shade to black.
16	1	5	1					2	2	2	Dark brown-drab.
17	1			2			1				Bright red.
18	1						1				Red, and every shade to black.
19	1				1						Steel-gray, at 180° F.
20	1					1					

(3) *Bronzing liquors for zinc by simple immersion*

Number	Water	Iron nitrate	Tin protochloride	Copper sulphate	Iron chloride	Lead chloride	Potassium carbonate	Potassium sulphocyanide	Sodium hyposulphite	Garrancine infusion	Logwood infusion	Result
21	pt. 1	dr. 5	dr.	dr.	dr.	oz.	dr.	dr.	dr.			Black.
22	1		1									Dark-gray.
23	1		1					1				"
24	2			1	1	*						Green-gray.
25												Red (boil).
26	2				1					*		Copper color.
27												Copper color (with agitation).
28	1			4			4		8			Purple (boil).
29	1			8								
30											*	

* Made to the consistence of cream.

rainbow, but the coating is so delicate that it must be protected by immediately dipping the article after drying into a quick-drying lacquer.

Golden-yellow.—There are many methods of providing small articles of brass with a coating of one color, various liquids being, for instance, used to produce determined shades of color on brass buttons. For a pure golden-yellow, the buttons are dipped for a few seconds in a perfectly neutral (free from acid) solution of copper acetate. A gray-green shade is produced by repeatedly dipping them in a dilute solution of copper chloride, and drying after each dipping. A violet tint is obtained by heating the buttons to a temperature at which oxidation does not take place, and rubbing them with a tuft of cotton dipped in a solution of antimony in hydrochloric acid.

Gold color.—For the production of the beautiful gold color possessed by many French articles of brass the following process may be used: Dissolve 1.76 oz. of caustic soda and 1.41 oz. of milk sugar (lactose) in 2.11 pints of water. Boil the solution for 15 minutes, and after taking it from the fire mix it with 1.41 oz. of a cold concentrated solution of copper sulphate. The red precipitate of cuprous oxide, which is immediately formed, deposits on cooling at the bottom of the vessel. The polished articles resting upon a wooden sieve are then placed in the vessel containing the solution. After about a minute, the sieve is taken out to ascertain how far the operation has progressed; it is then replaced, and at the end of the second minute the golden color is generally dark enough. The sieve is then taken out, and the articles after washing are dried in sawdust. By allowing the articles to remain for a longer time in the solution they soon acquire a greenish tint, which soon becomes yellow and then bluish-green, until finally the iridescent colors are formed. In order to obtain a uniform coloration it is necessary to produce the color slowly, which is best attained at a temperature of from 132 to 136° F. The bath can be repeatedly used and kept for a long time in well-stoppered

bottles. If partly exhausted, it can be restored by an addition of $\frac{1}{3}$ oz. of caustic soda, sufficient water to replace that lost by evaporation, heating to the boiling-point, and finally adding $\frac{7}{8}$ oz. of cold solution of copper sulphate.

Silver color.—To produce a silver color on brass, proceed as follows: Dissolve in a well-glazed vessel, $1\frac{1}{2}$ oz. of pulverized cream of tartar (potassium bitartrate) and $\frac{7}{10}$ ounce of tartar emetic (antimony-potassium tartrate) in 2.11 pints of hot water, and add to the solution $1\frac{3}{4}$ oz. of hydrochloric acid, $4\frac{1}{3}$ oz. of granulated or pulverized tin, and 1 oz. of pulverized antimony. Dip the article to be coated in the solution heated to the boiling point. After boiling from 15 to 30 minutes, they will be provided with a beautiful lustrous coating which is hard and durable.

Browning liquor for copper.—Add acetic acid to $\frac{11}{10}$ ounce of ammonium chloride until blue litmus paper dipped in the liquor turns red. Then add $\frac{1}{3}$ ounce of sal-ammoniac and sufficient water to make 2.11 pints. With the solution thus obtained, repeatedly moisten the copper surfaces, rubbing after each application until the desired brown tint is produced.

For coloring brass, Ebermayer of Nürnberg gives the following directions: (1) Eight parts of copper sulphate, 2 of sal-ammoniac, and 100 of water give by boiling a greenish color. (2) Ten parts of potassium chlorate, 10 of copper sulphate, and 1000 of water give by boiling a brown-orange to cinnamon-brown color. (3) By dissolving 8 parts of copper sulphate in 100 of water, and adding about 100 parts of caustic soda until a precipitate is formed, and boiling the articles in the solution, they acquire a greenish-brown color, which can be made darker by the addition of rouge. (4) With 50 parts of caustic soda, 50 of antimony sulphide, and 500 of water, and boiling, a light fig-brown color is obtained. (5) Boil 29 parts of copper sulphate, 20 of sodium hyposulphite, and 10 of cream of tartar in 400 of water. The brass first acquires a rose color, and then a blue color. By adding 20 parts of ammonium-iron sulphate and 20 of sodium hyposulphite, the colors change from yellow to rose

and blue after the latter, yellow again makes its appearance, and finally a beautiful gray is formed. (6) A mixture of 400 parts of water, 20 of potassium chlorate, and 10 of nickel salt (nickel-ammonium sulphate) give, after boiling for some time, a brown color, which is not formed if the sheet has been pickled. (7) A mixture of 250 parts of water, 5 of potassium chlorate, 2 of nickel carbonate, and 5 of nickel salt give, after boiling for some time, a brown-yellow color playing into a magnificent red. (8) A mixture of 250 parts of water, 5 of potassium chlorate, and 10 of nickel salt give a beautiful dark brown. (9) A mixture of 250 parts of water, 5 of orpiment (arsenic trisulphide) and 10 of crystallized soda give at first a beautiful red which passes into blue, then into pale blue, and finally becomes white. (10) A mixture of 250 parts of water, 5 of nickel salt, 5 of copper sulphate, and 5 of potassium chlorate give a well-covering yellow-brown color. (11) A mixture of 100 parts of water, 1 of potassium sulphide, and 5 of ammonia. The articles being allowed to lie in a closed vessel finally acquire a very beautiful blue color.

Coloring soft solders.—For giving the solder used in soldering copper the same color as the latter, first prepare a saturated solution of pure copper sulphate and apply it to the solder. Then by touching the solder with an iron or steel wire the latter becomes covered with a film of copper, which can be augmented as much as desired by repeated moistening with the solution of copper sulphate and touching with the wire. If the soldering is to show a yellow color, mix 1 part of saturated solution of zinc sulphate with 2 parts of copper sulphate, apply the mixture to the coppered place, and rub the latter with a zinc rod. If the soldered place is to be gilded, copper it as above described, then coat it with a solution of gum or isinglass, and strew bronze powder upon it. This forms a surface which, when the gum is dry, can be polished.

Bronzing of copper, bronze-metal, and brass.—Black bronzing is produced by brushing the metals with dilute nitric

acid containing a small quantity of silver in solution, and blazing off over the fire. This operation is repeated if after again brushing the articles with the acid, and blazing off, the color is not sufficiently deep. Nitric acid which has been used for dissolving fine silver and then poured off is most suitable for the purpose. A bismuth solution may also be used for producing this black, after which the articles are coated with lacquer. Brass may be bronzed black as follows: Dissolve copper in an excess of nitric acid, dilute the resulting liquid with a large quantity of rain water, apply it to the warmed brass, allow to dry in a warm place, and finally rub with a brush or with leather. Or, amalgamate the brass by brushing it with solution of mercuric nitrate, and convert the mercury on the surface into black mercury sulphide by means of potassium sulphide solution.

Brown bronze color is produced in the same manner as black, but besides silver the nitric acid must contain copper. Another method is as follows: Dissolve 1 oz. of sal-ammoniac and $\frac{1}{3}$ oz. of oxalic acid in $\frac{1}{2}$ pint of water, and brush the metal several times with the solution. Sulphuretted hydrogen will also produce a brown color. Dissolve potassium sulphide in 30 parts of water, pour the solution into shallow earthenware vessels, and place the latter in a room protected from draught. Put the articles to be bronzed near the vessels. The object is still more rapidly attained by placing the articles over the vessels with the potassium sulphide solution. This method of bronzing is especially suitable for articles soldered with soft solder which for that reason cannot be exposed to the fire.

Red-brown or copper-brown upon copper is produced by brushing the articles with a paste-like bronze consisting of a mixture of 1 part horn shavings, 4 parts copper acetate, 4 parts rouge, and some vinegar; or by placing them in a liquid bronze prepared as follows: Boil a solution of 2 parts copper acetate and 1 of sal-ammoniac in vinegar; remove the scum, dilute with water, allow to settle; pour off the supernatant liquid, boil again a porcelain dish, and quickly pour

Surface Coloring of Alloys

it over the copper articles. The liquor should be much diluted, the metallic articles carefully freed from grease, and rest on a wooden grate in a vessel which is immediately placed over the fire and the fluid brought to the boiling point; finally rinse in clean water.

A green bronze color is produced as follows: Dissolve a mixture of sal-ammoniac, $\frac{1}{2}$ oz.; argol (cream of tartar), 1 oz.; and common salt, 2 oz., in $\frac{1}{2}$ pint of vinegar. To this solution add $2\frac{3}{4}$ oz. of cupric nitrate solution; brush the articles with the resulting liquid, and allow to dry.

Coloring zinc.—The direct coloring of zinc, according to existing directions, does not yield satisfactory results, and it is therefore advisable first to copper the zinc and then color the coppering. Experiments in coloring zinc black with alcoholic solution of antimony chloride according to Dullos's process gave no useful results. Puscher's method is better. According to it the objects are dipped in a boiling solution of 5 oz. of pure iron sulphate and 3 oz. of sal-ammoniac in $2\frac{1}{2}$ quarts of water. The loose black precipitate deposited upon the objects is removed by brushing; they are again dipped in the hot solution, and then held over a coal fire until the sal-ammoniac evaporates. By repeating the operation three or four times a firmly adhering black coating is formed.

Gray, yellow, brown to black colors on zinc are obtained by bringing the articles into a bath which contains 6 to 8 quarts of water, $3\frac{1}{2}$ oz. of nickel-ammonium sulphate, $3\frac{1}{2}$ oz. of copper sulphate, and $3\frac{1}{2}$ oz. of potassium chlorate. The bath is to be heated to 140° F. By increasing the copper sulphate a dark color is obtained, and a lighter one with the use of a large proportion of nickel salt. The correct proportions for the determined shades will soon be learned by practice. When colored, the articles are thoroughly rinsed, dried without rubbing in warm sawdust, and finally rubbed with a woollen rag moistened with linseed oil, whereby they acquire deep luster, and the coating becomes more durable.

A kind of bronzing on zinc is obtained by rubbing it with a paste of pipeclay to which has been added a solution of

1 part by weight of crystallized copper acetate, 1 part of tartar, and 2 parts of crystallized soda.

Red-brown on zinc.—Rub with solution of copper chloride in liquid ammonia.

Yellow-brown shades on zinc.—Rub with solution of copper chloride in vinegar.

Browning gun-barrels.—Apply a mixture of equal parts of antimony trichloride and olive oil. Allow the mixture to act for 12 or 14 hours, then remove the excess with a woollen rag, and repeat the application. When the second application has acted for 12 to 24 hours, the iron or steel will be coated with a bronze-colored layer of iron oxide with antimony, which resists the action of the air, and may be made lustrous by brushing with a waxed brush.

A lustrous black on iron is obtained by the application of solution of sulphur in turpentine prepared by boiling on the water-bath. After the evaporation of the turpentine a thin layer of sulphur remains upon the iron, which on heating the article immediately combines with the metal.

A lustrous black is also obtained by freeing the iron articles from grease, pickling, and after drying, coating with sulphur balsam (sulphur dissolved in linseed oil) and burning in at a dark-red heat. If pickling is omitted, coating with sulphur balsam and burning-in must be repeated two or three times.

The same effect is produced by applying a mixture of 3 parts sulphur and 1 part graphite with turpentine, and heating in the muffle.

According to Böttger, a durable blue on iron and steel may be obtained by dipping the article in a $\frac{1}{2}\%$ solution of red prussiate of potash (potassium ferrocyanide) mixed with an equal volume of a $\frac{1}{2}\%$ iron chloride solution.

A brown-black coating with bronze luster on iron is obtained by heating the bright iron objects and brushing them over with concentrated solution of potassium bichromate. When dry, heat them over a charcoal fire, and wash until the water running off shows no longer a yellow color. Repeat

the operation two or three times. A similar coating is obtained by heating the iron objects with a solution of 10 parts by weight of iron sulphate and 1 part of sal-ammoniac in water.

To give iron a silvery appearance with high luster, scour the polished and pickled iron objects with a solution prepared as follows: Heat moderately $1\frac{1}{2}$ oz. of antimony chloride, 0.35 oz. of pulverized arsenious acid (white arsenic), 2.82 oz. of elutriated bloodstone (hematite or iron oxide) with 1 quart of 90% alcohol on a water-bath for half an hour. Part solution takes place. Dip into this liquor a tuft of cotton and go over the iron portions, using slight pressure. A thin film of arsenic and antimony is thereby deposited, which is the more lustrous the more carefully the iron has previously been polished.

On tin, a bronze-like patina may be produced by brushing the object with a solution of $1\frac{3}{4}$ oz. of copper sulphate and a like quantity of iron sulphate in 1 quart of water, and moistening, when dry, with a solution of $3\frac{1}{2}$ oz. of copper acetate in $10\frac{1}{2}$ oz. of vinegar. When dry, polish the object with a soft waxed brush and some rouge. The coating thus obtained is, however, not very durable, and must be protected by a coat of lacquer.

Warm sepia-brown tone on tin and its alloys.—Brush the object over with a solution of 1 part platinum chloride in 10 parts of water; allow the coating to dry, then rinse in water, and after drying again, rub with a soft brush until the desired brown luster appears. The coating is quite durable.

Oxidizing silver.—A blue-black color is produced by placing the articles in a solution of potassium sulphide diluted with spirits of sal-ammoniac. Allow to remain until the desired dark tone is produced, then wash, dry, and polish.

A brownish tint is obtained by using a solution of equal parts of copper sulphate and sal-ammoniac in vinegar.

A yellow color is imparted to silvered articles by immersion in a hot concentrated solution of copper chloride; rinsing, and drying.

Dipping brass.—These are yellow brass alloys, known as 7-oz.; 8-oz.; 9-oz.; and even 10-oz. dip. The alloys consist of copper and zinc only, as lead spoils the color when dipped. A good bright dip for brass which is fumeless is the following: sulphuric acid, 10 lb.; niter, 2 lb.; and water, 5 lb. Have the water in an earthenware jar, and add the acid gradually to the water in which the niter has been dissolved. As the acid heats the water, allow time to cool, and do not work the solution until it is cold.

Bright dip for German silver.—Yellow aqua fortis (38°), 2 gallons; sulphuric acid (66°), 1 gallon; water, 1 pint; and muriatic acid, $\frac{1}{2}$ oz.

Dip coppering solution.—Water, 1 gallon; copper sulphate, 4 oz.; sulphuric acid, 4 fluid oz.—use cold.

CHAPTER XXIX

FOUNDRY UTILIZATION OF SCRAP METALS

NATURALLY, new metals are the starting point for all alloys used in engineering, and just as naturally, time changes the new alloys into scrap. The machine wears out, or the casting itself breaks or wears out, and comes to be regarded, not as a casting, but as a piece of metal having only a certain scrap-metal value.

Scrap metals not uniform.—As there are many different kinds of alloys in service, it is impossible for scrap metals to be uniformly of the same composition. An attempt is generally made by the dealers to sort and classify the scrap, and to a certain extent this can be done; but there are some alloys very difficult to disentangle and segregate, and frequently it will happen these latter alloys are the very ones that will cause trouble. Take aluminum bronze, for instance: in the form of scrap this metal cannot always be detected, and becoming mixed with machinery scrap composed of copper-tin-zinc alloys it is capable of causing much annoyance after the metal is melted, owing to the aluminum thus introduced, which ruins the metal for anything but the very cheapest class of work.

Aluminum in scrap.—Manganese bronze also contains aluminum, and when such castings have been machined all over and have become dirty, they also get mixed with machinery scrap to cause trouble after the metal is melted, because then is the time the presence of aluminum can be detected, when the metal is all ready, and the molds are waiting for it. Under such circumstances it has to be ingoted and stored, or diverted to inferior uses.

When a heat of bronze made of scrap metal is found to contain aluminum after it has been skimmed off ready for pouring into molds, it is seldom that it can be used for the purpose originally intended, and usually it will be ingoted and a fresh start made with another heat. The problem then is to use up the contaminated material without spoiling castings. As the percentage of aluminum in the pigged heat is unknown, if it is the intention to use it up by making small additions to the regular metals, it will be necessary to make a test heat to determine just how much of the aluminized material can be used at a time. This will depend to some extent upon the cleanliness of the metal with which it is expected to be mixed. If the latter is oxidized, some of the aluminum in the addition will be oxidized in deoxidizing the alloy to which it is added in an attempt to work it off. A small amount of aluminum can be added to red brass and bronze without showing its presence and will act as a deoxidizer of the same, though it is a dangerous metal to use in this capacity. If metal free from oxygen is treated with aluminum, the latter will show, because it will remain in the metal as a part of the alloy, instead of being slagged off as a deoxidizer as it will in the case of drossy metal. Thus, in using bronze contaminated by aluminum, by proportioning it among clean heats, it is possible to get erratic results. Sometimes the aluminum may show on the castings, sometimes not, using the same proportion of the scrap; it will depend upon whether the treated metal happens to be clean or oxidized, and this in turn depends in large degree upon how it was melted.

Silicon in scrap metals.—Another troublesome element which is coming into use in alloys is silicon. As a troublemaker this is worse than aluminum in the case of the ordinary red metals used in most brass foundries, because a little silicon and a little lead together produce an astonishingly large amount of dross, which is precipitated on the surface of the castings in the form of a grayish powder, which produces pits of irregular shape too deep to be machined away.

Phosphorus hurtful.—Another trouble-maker found in the scrap-pile is phosphorus. This element, however, is not so bad as aluminum and silicon. On account of the uncertain composition of scrap, many manufacturers never attempt to use any that would have to be obtained from outside their own plants; but there are others who use nothing but scrap metals, and of the latter some foundrymen really imagine that “metal mixtures” can be formulated which will consist of all scrap metals, and that such mixtures are better and cheaper than alloys made to formula using virgin metals. In some cases it is undoubtedly cheaper to use scrap metals in preference to virgin metals, or even ingot metal, but these cases are not as numerous as many founders believe.

Using scrap metal.—Scrap can be used intelligently and unintelligently; it is used intelligently when its composition is known within limits that will permit of the new alloy approximating the composition most suited to the class of castings being made. Scrap is being used intelligently when by its means some metal is added which will form a part of the desired alloy; thus, yellow brass of known composition forms a good medium of adding zinc to alloys where zinc is required, and so with other alloys. Metals high in lead or tin can be used to add those elements provided in the case of leaded alloys they were not held together by the use of sulphur. Most mixtures of copper and lead in proportions over 35% of the latter are sulphurized metals—that is, sulphur in some form has been added to prevent segregation of the lead on the alloy solidifying. Sulphur added to red brass or bronze would in all probability produce porous castings.

Another danger arising from the promiscuous use of scrap metals is that an entirely wrong mixture may result from melting together a miscellaneous assortment of red brass, bronze, and yellow brass. Thus, any alloy containing a considerable percentage of tin will also have its casting properties injured by a correspondingly high percentage of zinc. The castings will be rough, owing to the metal burning onto

the sand. They are also likely to be brittle. Many brass-founders make up mixtures like the following:

Doubtful mixtures from scrap metals

No. 1	Pounds	No. 2	Pounds
Copper (scrap).....	28	Copper.....	25
Red brass.....	50	Scrap red brass.....	71
Yellow brass.....	14	Tin.....	1
Lead.....	5	Lead.....	1½
	—	Zinc.....	1½
	97		100

The unknown quantities in the first formula are the red and yellow brass; the second formula is not so bad, as there is only one unknown quantity—the red brass. The copper, tin, lead, and zinc additions make the following alloy: copper, 86.20%; tin, 3.45%; zinc, 5.18%; and lead, 5.17%; and judging from the oddity of the figures, it just happened that this formula was arrived at. It might have been worse, it merely happens this formula is a passable red brass. But what of the red-brass scrap? The mixture was formulated in the hope of getting something for nothing; the red brass was relied upon to furnish more tin than was actually put into the mixture. If the red brass was carefully selected, the alloy would be fairly good, and it would be justifiable, provided the red-brass scrap was “home scrap,” because then it would require to be used to best advantage, and some general idea would prevail as to its composition. To make such an alloy as the above, using red-brass scrap bought in the open market, would be little economy; and would very likely show a loss after everything had been calculated.

Loss in melting.—In melting miscellaneous red-brass scrap, a loss has to be taken into account, owing to dirt and dross; and very often this matter is entirely forgotten, or ignored. Then there is the uncertainty of the composition, the chance of some foreign and injurious metal like aluminum bronze or manganese bronze getting into some heat; then the higher production loss incident to the use of scrap, and when all is figured against the alloy, it will be found in the majority of cases that money would have been saved by buying grade

No. 3 ingot metal, tentative specifications of the American Society for Testing Materials. This ingot, which can be obtained from reputable manufacturers of ingot metals, would have the following composition by analysis: copper, 83% ; tin, 4% ; lead, 6% ; and zinc, 7%.

Its physical properties would be known as from 28,000 to 33,000 lb. per sq. in. tensile strength; 15 to 20% elongation in 2 inches; 20 to 26% reduction of area; Brinell hardness number, 55 to 60; shrinkage, 0.125 inch (the latter low, making a good easy casting alloy); and weight, 0.31 lb. per cu. in. The ingot would not only be a better, cleaner, stronger metal, with a low melting loss, known composition, and physical properties, but in addition the chances are greatly in favor of its cost per pound being below that of the scrap-metal mixture. This is the better mixture of the two cited as examples, both of which are taken from actual practice.

Referring to the first mixture, cited, consisting of 50 lb. of red brass, 28 lb. of copper, 14 lb. of yellow brass, and 5 lb. of lead; and let us assume that the yellow brass was scrap sheet clippings, and not a general assortment of cast yellow scrap: The clippings might consist of copper, 70%, and zinc, 30%; and omitting consideration of the red brass, the yellow brass, copper, and lead would give an alloy of the following proportions: copper, 80.40% ; zinc, 9.00% ; and lead, 10.60%. The red brass was expected to furnish the tin required to make the mixture any good, but it is doubtful if the red brass scrap would introduce 3% of tin, as to do this it would have to carry approximately 6% of tin, and very little red brass scrap will do this. The alloy made then is greatly inferior to grade No. 4 ingot, A. S. T. M. specifications, which has the following composition: copper, 77.00; tin, 3; lead, 10; and zinc, 10%.

I have tried to show that in general nothing is gained by the use of miscellaneous scrap metals, and that it is cheaper to buy ingot metal of known composition and physical properties than to mix together red and yellow brass scrap and add lead thereby producing a "mongrel" mixture, which will

differ in composition with every heat and will inevitably entail high production losses in making castings. Secondary metals, have, of course, to be used over again; they cannot be thrown away, but in these times of aluminum carrying alloys, scrap of lost antecedents should be melted in large quantity, refined, re-alloyed, and cast into ingots of standard composition, so that when put into the hands of the foundryman it is a simple operation to melt it again and cast it into

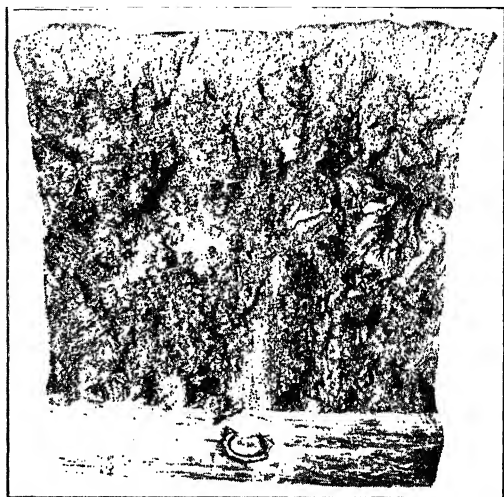


Figure 105.—Surface of fractured ingot of good composition.

useful forms once more, with no chances being taken of running into unlooked-for losses. In figure 105 is shown the fractured surface of an ingot of good red brass.

Regarding ingot metals, the American Society for Testing Materials appointed a committee, known as Committee B-2, for the purpose of drawing up tentative specifications for brass ingot metal, graded and ungraded, for sand castings. They * are as follows:

Serial Designation: B 30-21 T.—These specifications are issued under the fixed designation B 39; the final number

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indicates the year of original issue, or in the case of revision, the year of last revision:

SPECIFICATIONS FOR INGOT METAL

1. These specifications cover brass ingot metal for sand castings, known commercially as red and yellow brass ingot, made wholly or partly from scrap materials. Seven typical alloys are specified and are designated Grades No. 1 to 7, in accordance with their decreasing copper content, as specified in Section 3. These specifications also cover brass ingot metal which has no grade limit, designated as ungraded material such as a specific lot of ingots, having a stated composition suitable for buyers' needs.

I. MANUFACTURE

2. The manufacturer shall use care to have each lot of ingot metal as uniform in quality as possible. Individual ingots of any lot shall not show an extreme variation between the high and low copper percentages of more than 2.5%, and between the high and low percentages of the other main constituents, except zinc, of more than 1.5%.

II. CHEMICAL PROPERTIES AND TESTS

3. The graded alloys shall conform to the following requirements as to chemical composition, within the limits specified in section 4:

Alloy	Copper, %	Tin, %	Lead, %	Zinc, %	Iron, %	Anti- mony, % (max.)	Alu- minum, % (max.)	Sulphur, % (max.)
1	87	8	2*	3	0.25	0.25	None	0.05
2	85	5	5	5	0.35	0.25	"	0.05
3	83	4	6	7	0.35	0.25	"	0.05
4	77	3	10	10	0.40	0.35	"	0.05
5	76	2	6	16	0.40	0.25	"	0.05
6	65	1 (max.)	2	33	0.50	0.20	" *	0.05
7	60	1½ (max.)	3	37	1.00	0.20	" *	0.05

* See table following.

Permissible variations.—4. The following permissible variations in the percentages of the desired elements specified in section 3 will be allowed, but shall not apply to the maximum percentage of impurities specified:

Percentage of element specified	Permissible variations over and under the specified value Units of per cent
Not over 5 per cent.....	0.50
Not over 5 to 15 per cent, inc.....	0.75
Over 15 per cent.....	1.00

Samples for chemical analysis.—5. (a) Ten ingots shall be selected by the inspector to represent 40,000 lb., and five ingots for less than carload lots.

(b) The samples for chemical analysis may be taken either by sawing, drilling, or milling the ingots, and shall represent the average cross-section.

(c) The saw, drill, cutter, or other tool used shall be thoroughly cleaned. No lubricant shall be used in the operation, and the sawings or metal chips shall be carefully treated with a magnet to remove any particles of steel introduced in taking the samples.

6. To be prepared by the Committee. This section refers to the methods of chemical analysis to be used.

III. MARKING

7. The designating mark of the manufacturer, the proper lot number, and the numerical designation of the grade supplied, shall be marked on each ingot for identification.

IV. INSPECTION AND REJECTION

8. (a) Inspection may be made at the manufacturer's works where the ingots are made, or at the point at which they are received, at the option of the purchaser.

(b) If the purchaser elects to have inspection made at the manufacturer's works, the inspector representing the purchaser shall have free entry at all times while work on the contract of the purchaser is being performed, to all parts of the manufacturer's works which concern the manufacture of the material ordered. The manufacturer shall afford the inspector, free of cost, all reasonable facilities to satisfy him that the material is being furnished in accordance with these specifications. All tests and inspection shall be so conducted as not to interfere unnecessarily with the operation of the works.

9. If the test ingots selected to represent a lot fail to conform to the requirements specified in sections 3 and 4, all ingots in such lot shall be rejected.

V. CLAIMS

10. Claims, to be considered, shall be made in writing within 30 days of receipt of material at the purchaser's plant, and the results of the purchaser's tests shall be given. The shipper shall

within one week of receipt of such claim, either agree to satisfy the claim or send a representative to the purchaser's plant to re-sample the shipment, as specified in section 5. Samples so taken shall be sealed and submitted to a mutually agreeable umpire, whose determination shall be final.

11. The expense of umpire analysis shall be paid by the loser, or divided in proportion to the concession made in case of a compromise. In case of rejection being established, the damages shall be limited to the payment of freight both ways by the manufacturer for the substitution of an equivalent weight of ingot metal meeting these specifications.

The data given in table 89 do not constitute a part of the above specifications, but they are given merely to indicate to the purchaser the physical properties of the various alloys specified which can be expected of carefully manufactured alloys of the formulas indicated, and to constitute a guide to the purchaser in selecting the grade best suited for meeting the service condition for which the ingot metal is to be used.

A study of the specifications of the American Society for Testing Materials will show that a careful painstaking effort has been made to place at the disposal of the average brass-founder a supply of brass ingot metal which can be depended upon as to formula and physical properties, and can be obtained at a cost usually below that of new metals. While it is difficult to conceive that there might be manufacturers of ingot who would refuse to work to such specifications, should the improbable happen, the prospective purchaser can decide that such objection is not made in his interest, and therefore, his duty is plain, because there are reputable manufacturers who not only will work to the A. T. S. M., but to any other specifications the brass-founder may desire.

Foundry working to specifications.—In operating a brass foundry, an effort should always be made to work to specifications in the case of all the alloys that are going to be used. Every founder should draw up his own specifications for formulas to fit the kind of castings he expects to be called upon to make, bearing in mind that it will be most economical to keep to standard formulas as much as possible. If scrap

TABLE 89.—Physical properties of brass ingot metal alloys

Alloy, Grade No.	Desired composition				Tensile strength, lb. per sq. in. *	Elongation, in 2 in., per cent. *	Reduction of area, per cent. *	Brinell hardness (500 kg. for 30 sec.)	Shrinkage, in. per ft.	Weight, lb. per cu. in.
	Copper, %	Tin, %	Lead, %	Zinc, %						
1	87	8	2	3	30-36,000	25-30	25-30	.....	0.125	0.31
2	85	5	5	5	27-33,000	16-20	15-20	50-60	0.14	0.31
3	83	4	6	7	28-33,000	15-20	20-26	55-60	0.125	0.31
4	77	3	10	10	23-28,000	10-15	10-15	50-55	0.125	0.32
5	76	2	6	16	25-30,000	20-30	20-30	43-48	0.18	0.31
6	65	....	2	33	25-30,000	20-30	25-35	37-42	0.18	0.30
7	60	....	3	37	30-45,000	15-25	20-30	43-48	0.20	0.29

* The tension tests were made on "sand cast-to-size" test specimens.

Grade No.	Example of uses	Foundry manipulation	Characteristics
1	High-grade steam metal.....	Easily handled.....	Machines well.
2	High-grade red brass for general service.	Easily handled.....	Machines more readily than No. 1.
3	Medium grade red brass for general service.	Easily handled.....	Machines more readily than No. 1.
4	Valves and fittings for low pressures.	Not difficult.....	Machines very easily.
5	Reddish-yellow alloy for air, gas, and water fittings.	Not difficult.....	Machines very easily.
6	Yellow brass for general service.....	Difficult. Aluminum up to 0.3% improves casting properties, but increases shrinkage.	Machines poorly. Not suitable for bearings or water-pressure fittings.
7	Plumbers' flanges, scupper pipes, etc.	Very difficult. Aluminum up to 0.3% improves casting properties, but increases shrinkage.	Hard to machine. Not suitable for bearings or water-pressure fittings.

brass is plentiful nearby, it may pay to use it even in preference to ingot metal, but to decide this question do not allow prejudice to enter into the matter in any way.

Merit of scrap.—Judge it on its merits; run a month on the scrap, keeping a careful watch on the cost of using it; ascertain the loss of metal due to dross and dirt; and the expense of feeding the loose material into the furnaces. Then run a month on ingot of the composition that was desired with the scrap, and by comparing the scrap figures with those for the ingot metal, decide which to use, and having once decided which is the most economical, stick to it.

The subject of scrap metals and how to use them is a most interesting one to brass-founders, because modern alloys cannot be mixed together and re-melted to make castings as scrap metals could in the days before aluminum, silicon, and high phosphorous alloys. The fact that they are often so mixed, melted, and used, is not proof that it pays to do so. On the subject of ingot metals some very interesting remarks are contained in a little bulletin issued by the Ajax Metal Co., from which we quote as follows:

The use of ingot metal in the foundry, already a common practice among the more advanced foundrymen, is rapidly increasing owing to the growing knowledge of its many advantages. The first great advantage of ingot metal is economy, both in first cost and increased production. This is not an argument in favor of cheapness, as economy and cheapness do not always go hand-in-hand. As with other things, it is possible to buy ingot metal too cheaply. Some users of ingot metal in the past have suffered through a desire to buy cheaply and without due regard to what they got for their money, or to the standing and reliability of the firm from whom they bought. Neither is this an argument in favor of high price, but of high quality. Those that underpay, underget. Less value is often given than is paid for, no matter how little may be paid, and the results are frequently very costly. Ingots made by reputable concerns have the detrimental impurities eliminated, the resulting metal being fully equivalent to that made from virgin metals, and far superior to that made from promiscuous scrap. The advantages of ingots may be stated as follows:

They are ready to charge into the furnace, all that is required is to melt them under charcoal. The melting is done more rapidly because the metal is already alloyed and as a consequence its melt-

ing point is lower. The loss in melting is reduced; the ingots are clean, solid, and all metal. The liability to error in making mixtures is entirely eliminated, the composition of the ingots being definite, uniform, and known to be correct. The manufacturer of ingot metal usually guarantees his product, should loss result to the founder due to mistakes in the composition of the ingot supplied, or because any injurious impurity has not been entirely eliminated, the manufacturer of the ingot has to take his share of the blame and loss. The dealer in scrap metal assumes no liability for castings spoiled through the introduction of injurious impurities.

The author of this volume has presented his views on the subject of scrap and ingot metals rather fully because it is his

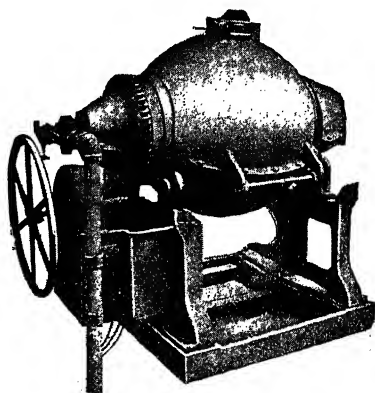


Figure 106.—Continuous revolving, non-crucible melting and refining furnace (Monarch "D").

belief that the use of ingot metals in foundries in preference to miscellaneous scrap is to the interest of the brass-founder more than anyone else. It would materially assist in reducing the losses in making brass and bronze castings. How serious these losses are is shown by Charles L. Parsons, former Chief of the Division of Mineral Technology of the U. S. Bureau of Mines, in his preface to Bulletin 73 (1914), "Brass-Furnace Practice in the United States" by H. W. Gillett, as follows:

There are in America some 3600 plants melting brass and bronze, and 1000 of these melt non-ferrous metals exclusively. The alloys

of copper, zinc, tin, lead, or other elements in cast or wrought form play an important rôle in our daily life. Allowing for the present recovery of waste metal, it appears that in current practice, between the purchase of the raw material and the completion of the finished product, at least 5% of the original metal is lost. Zinc passes into the atmosphere through the furnace stack; the other metals in the alloy may be oxidized and pass into the stack, may be spilled in the furnace ash, or in one way or another may not be

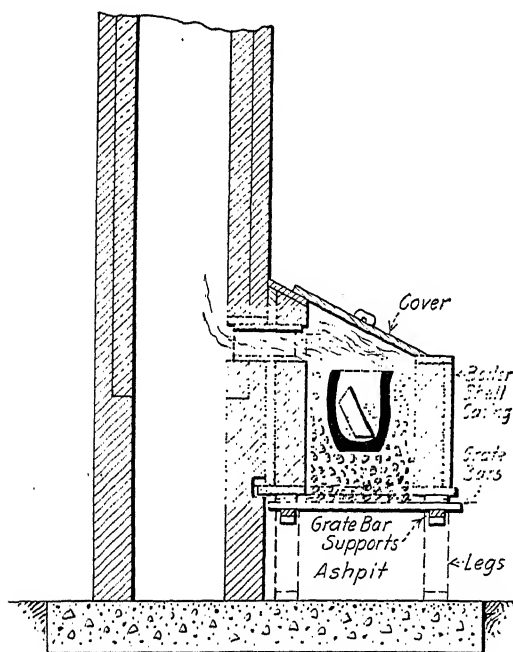


Figure 107.—Fire assay and melting furnace.

completely recovered. In the melting of non-ferrous alloys, taking into consideration all such alloys and all furnaces and fuels used, it is shown that from 90 to 95% of the heat units in the fuel do no useful work. On the basis of \$120,000,000 being the value of the metal passing through brass and bronze furnaces each year, a 2½% melting loss, equivalent to 5% loss on metal bought, means an annual loss of \$3,000,000 in metal alone. Simply reducing the average metal loss to that of present best practice would mean a saving of over \$1,500,000 a year. If fuel efficiency and crucible life could be brought from present average to best practice, \$500,000 more, at least, could be saved.

One of the most striking facts brought out by this investigation is the lack of proper control and proper records in most of our furnace practice. Gillett has concluded that it is doubtful if there are 50 firms in the United States that have daily furnace records which are exact enough to allow the correction of avoidable losses. The firms that keep proper records, and hence have the necessary knowledge, invariably employ a trained metallurgist to supervise the melting fur-

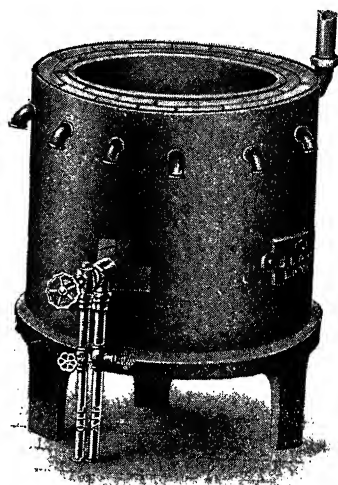


Figure 108.—Soft metal melting furnace
(Monarch "B").

naces, and these firms almost always have the lowest losses. That there is a wide lack of technical control is emphasized by reports of metal losses varying from 0.1% to 22%, and fuel efficiency from 1½ to 16%. The need for thorough technical control in the majority of our foundries and casting shops has been made evident by this investigation.

The melting of large quantities of scrap metals can be carried out in furnaces of the type shown in figure 106, which illustrates a revolving oil-fired furnace manufactured by the Monarch Engineering & Manufacturing Co. of Baltimore,

Maryland. The capacity of this furnace is from 250 to 2000 lb. per heat, and it will run down approximately 750 lb. of metal per hour. It consumes oil or gas at low pressure.

For making small melts for testing scrap, and making new combinations of metals, the furnace shown in figure 107 is very convenient, as it can be stood on the floor, and due to its desk-like shape it is very easily operated. It is also useful for making fire assays of metal-bearing material.

For making melts of soft metals, a furnace of the type shown in figure 108 is useful. This is also one of the Monarch Company's furnaces. It will be noted that it is fitted for oil or gas firing.

CHAPTER XXX

ANALYSIS OF BABBITT METALS

THE proposed revised tentative methods* of the American Society for Testing Materials for the chemical analysis of alloys of lead, tin, antimony, and copper are given below. The first is somewhat slow, but is recommended as giving the more accurate results where the analysis of these alloys is comparatively infrequent; while the second method is rapid and is suitable for control work, giving good results after the analyst has become familiar with it.

I. GENERAL METHOD

A. DETERMINATION OF LEAD, COPPER, ANTIMONY, AND TIN

Solutions required:

Mixed acid.—Dissolve 20 grams of potassium chloride (KCl) in 500 cubic centimeters (c.c.) of water, add 400 c.c. of hydrochloric acid (HCl) of 1.20 specific gravity; mix, and add 100 c.c. of nitric acid (HNO_3) of 1.42 specific gravity.

Alcohol-hydrochloric acid mixture.—Mix 400 c.c. of 95% ethyl alcohol and 100 c.c. of hydrochloric acid of 1.20 specific gravity.

Acid ammonium acetate.—To 500 c.c. of ammonia (NH_4OH) of 0.90 specific gravity, add 500 c.c. of water (distilled), and then acetic acid—80% strength—until slightly acid to litmus.

Method

Dissolve one gram of the finely divided alloy by boiling in 70 to 100 c.c. of "mixed acid" solution in a covered beaker.

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Add more mixed acid if a complete solution of the alloy is difficult to obtain, and continue boiling until evaporated to about 50 c.c. Add 5 c.c. of hydrochloric acid, 1.20 specific gravity, and cool in ice water until the bulk of lead chloride (PbCl_2) has crystallized out; then add slowly with constant stirring, 50 c.c. of 95% alcohol, continue stirring for a few minutes, and cool in ice water for 10 minutes.

Add 50 c.c. more alcohol from a pipette, allow to stand in ice water for 20 minutes, and filter through 9-c.m. (cubic millimeter) filter-paper into an 800-c.c. beaker. Wash by decantation three times with alcohol-hydrochloric acid mixture, and finally wash the paper twice with the same mixture. Wash the lead chloride from the paper back into the beaker; wash paper several times with hot water, catching the washings in beaker with the bulk of the chloride. Finally wash the paper with hot acid-ammonium acetate solution. Heat until all lead chloride is dissolved. Add 15 c.c. of a saturated solution of potassium bichromate ($\text{K}_2\text{Cr}_2\text{O}_7$); heat until precipitate is of good orange color; filter on weighed Gooch crucible; wash with water, alcohol and ether; dry at 110°C ., and weigh. Calculate percentage of lead by the empirical factor 63.75.

NOTE: With proper manipulation the lead chloride precipitate should contain consistently all but 0.003 gram of lead. During the heating of the acid-ammonium acetate to dissolve the lead chloride the solution should remain perfectly clear, any turbidity indicating the presence of tin or antimony, as even one milligram of each of these metals will cause a slight but distinct turbidity.

Tentative Methods for Analysis of Alloys

DETERMINATION OF COPPER AND ANTIMONY

Solutions required:

Potassium hydroxide.—Dissolve 100 grams of KOH in 500 c.c. of water.

Potassium cyanide.—Dissolve 3.5 grams of KCN in 1800 c.c. of water, and standardize against copper of known purity.

Method

See determination of lead.

Evaporate the filtrate from PbCl_2 filtration by boiling in the loosely covered 800-c.c. beaker, and finally take to dryness on a water-bath. Add 10 c.c. of KOH solution, and after a few minutes add 20 c.c. of 3% H_2O_2 (hydrogen peroxide). Add more KOH, if solution is acid, until an alkaline reaction is shown by litmus paper. Heat on the water-bath for 20 minutes, add 10 grams of ammonium oxalate, 10 grams of oxalic acid, and 200 c.c. of water, and heat to boiling. Pass in H_2S (hydrogen sulphide gas) for 45 minutes with solution near boiling; filter at once; and wash precipitate with hot water, catching washings with filtrate.

Wash the precipitate of copper and antimony sulphides from the filter-paper back into the beaker with the least amount of water possible; treat with 10 c.c. of KOH solution; heat on water-bath until the undissolved matter is distinctly black, filter through same paper into a 300-c.c. Erlenmeyer flask. Wash the precipitate with hot water.

(a) *Determination of copper by potassium cyanide titration.*

Dry and ignite the precipitate with paper in a small casserole, dissolve in nitric acid (sp. gr. 1.42), boil to expel nitrous fumes, neutralize with Na_2CO_3 (sodium carbonate), add a few drops of NH_4OH , and titrate with standard KCN solution.

(b) *Determination of copper by electrolytic method.*

See determination of copper by potassium cyanide titration.

Dry and ignite the sulphide precipitate in a small casserole, dissolve in 10 c.c. of HNO_3 (sp. gr. 1.42), boil until oxides of nitrogen are expelled, and add 50 c.c. of distilled water. Transfer to a tall 200-c.c. beaker, wash out casserole, add 5 c.c. of H_2SO_4 (sp. gr. 1.84), and determine copper by electrolysis. (See the determination of copper by the electrolytic method in the standard methods for chemical analyses

of manganese bronze (serial designation: B 27)* of the A. S. T. M.).

NOTES: 1. On the filter, after heating with KOH solution, the copper remains as sulphide with a small amount of lead sulphide which failed to be precipitated as chloride. If it is desired to determine this lead, it can be done by separation from the copper by ordinary methods.

2. If the amount of antimony and copper is small (less than 10 mg.) the lead which failed to be precipitated as chloride may also fail to come down as sulphide on passing H_2S through the oxalic solution. It will remain in the filtrate from the sulphides and be deposited electrolytically with the tin on the cathode. This can be prevented by adding an oxalic acid solution of a pure antimony salt containing about 100 mg. of antimony just before passing H_2S . In this case antimony must be determined on a separate portion.

3. If the amount of copper present is from 8 to 10 mg. or more, it should be determined by the electrolytic method. In this case, the small amount of lead precipitated as sulphide with the copper is deposited on the anode as PbO_2 and may be weighed, calculated to lead by factor 86.43 and added to that obtained under determinations of lead.

(c) Determination of antimony.

Solutions required:

Sodium thiosulphate.—Dissolve 24.8 g. of $Na_2S_2O_3 \cdot 5H_2O$ in 1000 c.c. of water, and allow to stand for 24 hours. Standardize against Antimony Metal C. P., using same quantity of reagents and same procedure as under method.

Method

See determination of copper by potassium cyanide method.

Add 50 c.c. of HCl (sp. gr. 1.20) to the KOH solution of antimony sulphide, and boil down to small volume until all arsenic has been expelled as arsenious chloride.

Add 25 c.c. of HCl (sp. gr. 1.20) and 1 gram of $KClO_3$, and boil until colorless. Filter into a 300-c.c. Erlenmeyer flask, through glass wool if sulphur has separated, wash out original flask with HCl (sp. gr. 1.20), cool, add 1 gram of

* A. S. T. M. Standards adopted in 1919, p. 20.

KI, 1 c.c. of CS_2 (carbon disulphide), and titrate with standard thiosulphate solution.

(d) *Determination of tin.*

Apparatus for Electrolysis

Electrodes.—Cylindrical cathodes of platinum wire gauze, 2 by $1\frac{3}{8}$ inch diameter.

Platinum wire spiral anodes.

Method

See determination of copper and antimony.

Concentrate the filtrate and washings from the precipitated sulphides, if necessary, to a volume of 200 c.c., and add 5 grams more of oxalic acid in case the amount of tin is over 0.5 gram. Electrolyze until the solution reacts alkaline, using a current of about 0.5 ampere. Remove the cylinder, wash twice with distilled water and once with 95% ethyl alcohol; dry at 110°C . and weigh.

NOTE: If the electrolysis is carried out over night it will usually be found that by morning the solution has become alkaline, and it may be taken for granted that the tin has all been precipitated on the cathode. The best results are obtained by regulating the current or the time to render the solution alkaline only a very short time before the cathode is to be removed. The cathode should be placed close to the bottom of the beaker to ensure proper agitation of the electrolyte.

(e) *Determination of arsenic.*

Solutions required:

Ferric chloride.—Solution of 1.43 specific gravity.

Ammonium carbonate.—Dissolve 75 grams in 500 c.c. of water.

Method

Weigh one gram of sample into a 250-c.c. distillation flask, and add 10 c.c. of ferric chloride solution, 60 c.c. of HCl

(sp. gr. 1.20), 20 c.c. of water, and 5 grams of KCl. Connect the flask with a condenser, heat slowly until solution is complete, and boil down to as small a volume as possible, catching distillate in a tall 400 c.c. beaker. Cool flask, add 50 c.c. of HCl (sp. gr. 1.20), and re-distill as before, catching distillate in the same beaker. Cool distillate and pass H_2S through for one hour, allow to settle, and filter the arsenious sulphide on a Gooch crucible. Wash twice with dilute HCl (1:4), then four times with cold water, three times with alcohol, and four times with CS_2 . Dry at 110°C . for 10 minutes, and weigh after cooling. Dissolve the arsenious sulphide with $(\text{NH}_4)_2\text{CO}_3$ (ammonium carbonate) solution, wash thoroughly with water, dry for 30 minutes at 110°C ., and re-weigh after cooling. The difference in weights multiplied by 0.60911 gives the percentage of arsenic.

II. RAPID METHOD FOR CONTROL WORK

A. DETERMINATION OF LEAD AND COPPER

Solutions required:

Lead acid.—Mix 300 c.c. of H_2SO_4 (sulphuric acid) of 1.84 specific gravity, and 1800 c.c. of distilled water. Dissolve 1 gram of lead acetate (c.p.) in 300 c.c. of distilled water, and add this to the hot solution, stirring meanwhile. Let stand at least 24 hours, and siphon through a thick asbestos filter.

Dilute alcohol for washing.—Mix equal parts of denatured alcohol and distilled water.

Method

(a) Determination of lead.

In a covered beaker of 300 c.c. capacity, dissolve 1 gram of the alloy in 20 c.c. of sulphuric acid of 1.84 specific gravity, heating the solution until the metal is completely decomposed, and the lead sulphate (PbSO_4) is white, and finally boil for half an hour. Allow to cool slightly, but not below 60°C .,

and add 100 c.c. of water in which has been dissolved 5 grams of tartaric acid. Allow this solution to stand for two hours, and filter on a weighed porcelain Gooch crucible, decanting as much of the solution as possible before bringing the precipitate on to the crucible. Wash with lead acid, retaining the filtrate and these washings for the copper determination. Remove the beaker containing these solutions and wash out the lead acid with dilute alcohol; set the Gooch crucible inside a porcelain crucible; dry and ignite for 5 minutes at the full heat of a Tirrill burner; cool, and weigh as PbSO_4 , which contains 68.29% lead.

(b) *Determination of copper.*

To the filtrate from the PbSO_4 , which contains the copper and which has been transferred to an Erlenmeyer flask, add NH_4OH (sp. gr. 0.90) until the solution is slightly alkaline; then add 2 c.c. of H_2SO_4 (sp. gr. 1.84); heat nearly to boiling; add 2 grams of Na_2SO_3 , and when this is entirely dissolved add 1 gram of KCNS dissolved in 10 c.c. of water. Shake well, and allow the precipitated CuCNS to settle for one hour while the solution is kept hot. Filter on a close filter-paper, wash with cold water, ignite paper, and precipitate in a porcelain crucible. Proceed by one of the two following methods:

(1) Dissolve in HNO_3 (sp. gr. 1.42), add 5 c.c. H_2SO_4 (sp. gr. 1.84); evaporate until fumes of H_2SO_4 are evolved. Dilute to about 100 c.c. with distilled water. Add 1.5 c.c. of HNO_3 (sp. gr. 1.42), and determine copper by electrolysis. (See the determination of copper by the electrolytic method, standard methods for chemical analysis of manganese bronze (serial designation: B 27-19) of the A. S. T. M.)

(2) Dissolving the ignited precipitate in HNO_3 (sp. gr. 1.42), as in (1); boil to expel nitrous fumes, neutralize with Na_2CO_3 , and determine volumetrically with cyanide as in A of General Method.

NOTE: If the amount of copper is very small it may escape detection by this method, in which case it should be determined as in A of General Method.

B. DETERMINATION OF ARSENIC, ANTIMONY, AND TIN

Apparatus

Arsenic still.—A condenser is made from glass tubing in the form of a letter S, about 18 inches long and $\frac{1}{2}$ inch inside diameter, tapering to about $\frac{1}{4}$ inch at the upper end, and to about $\frac{1}{8}$ inch at the lower end. One curve is nearly filled with water, and is submerged in cold water in a 500-c.c. beaker. The lower end dips into about 75 c.c. of water in a 300-c.c. beaker, and the upper end is connected by a delivery tube with a 300-c.c. Florence flask, closed with a rubber stopper, which is fitted with a delivery tube and a thermometer reaching to about one inch above the surface of the liquid in the flask.

Solutions required:

Iodine.—Dissolve 10.7 grams of iodine in 50 c.c. of distilled water which contains 20 grams of KI (potassium iodine) in a solution, and dilute to 1000 c.c. with distilled water. Standardize against pure tin having exactly the same conditions for titration as are specified for the analysis of the alloy. Each cubic centimeter is equivalent to approximately 0.00500 gram of tin, or 0.00315 gram of arsenic.

Potassium permanganate.—Dissolve 2.7 grams of KMnO_4 (potassium permanganate) in distilled water, filter through asbestos, and dilute to 1000 c.c. with distilled water. Standardize against pure antimony having exactly the same conditions for titration as are specified for the analysis of the alloy. Each cubic centimeter is equivalent to approximately 0.00500 gram of antimony or 0.00465 gram of iron.

Ferrous ammonium sulphate.—Dissolve 12.4 grams of ferrous ammonium sulphate crystals in 950 c.c. of distilled water, and add 50 c.c. of H_2SO_4 (sp. gr. 1.84).

Starch.—To 1000 c.c. of boiling water add a cold suspension of 6 grams of starch in 100 c.c. of distilled water; cool, add a few drops of chloroform, and mix thoroughly.

Method

(a) Determination of arsenic.

In a 300-c.c. Florence flask dissolve 0.5 gram of the alloy in exactly 8 c.c. of H_2SO_4 (sp. gr. 1.84). The metal must be finely divided, preferably in the form of thin foil-like shavings, although sawings or very fine drillings may be used. Heat the solution to boiling; cool, add about 5 c.c. of water and a bulk of about 0.5 c.c. of clean granulated pumice stone, and boil the covered solution very gently for about 5 minutes, or until the strong odor of SO_2 (sulphur dioxide) can no longer be detected. Finally, being careful to have 5 c.c. of water present, cool the solution to about 18°C ., and cautiously add 20 c.c. of HCl (sp. gr. 1.20). Insert in the flask a rubber stopper fitted with a thermometer and delivery tube, and connect the latter with the *S* condenser. Heat the solution to gentle boiling for from 10 to 15 minutes, keeping the vapor temperature at 107°C . for at least 5 minutes. Wash out the condenser into a 300-c.c. beaker and add an excess of about 2 grams of NaHCO_3 . Bring the volume of the solution to about 200 c.c.; warm to about 27°C ., and titrate with standard iodine solution and starch to the appearance of a deep blue color.

NOTE: A blank determination should be made on corresponding amounts of reagents treated as above, and the results should be corrected accordingly.

(b) Determination of antimony.

Cool the solution which remains in the flask after the arsenic distillation; add about 130 c.c. of cold freshly boiled distilled water, to which has been added about 3 c.c. of HCl (sp. gr. 1.20), and titrate with standard KMnO_4 solution to the appearance of a decided permanent pink color. From a burette add an excess of standard ferrous ammonium sulphate solution until the pink color is discharged, and then titrate with standard KMnO_4 solution to the reappearance of a pink color.

(c) Determination of tin.

If the sample does not contain 14% (or 0.07 gram) of antimony, add enough dissolved SbCl_3 to the solution to bring the antimony content up to about 0.07 gram for the purpose of ensuring perfect reduction of the tin and uniform conditions for the titration. Then add exactly 6 c.c. of H_2SO_4 (sp. gr. 1.84) and 60 c.c. of HCl (sp. gr. 1.20), and add about 6 inches of clean, soft No. 14 pure iron wire cut into 2-inch lengths and cleaned with dilute HCl just before using. Boil gently for $\frac{1}{2}$ hour, add about 6 inches more wire and boil $\frac{1}{2}$ hour longer. Remove from heat, close flask loosely with a rubber stopper, and allow about 2 minutes for all air to be expelled by hydrogen and acid vapors. Close flask tightly and quickly place it in cold water, cooling the solution to about 20°C . Transfer the solution quickly to a 500-c.c. beaker (leaving the iron wires in the flask) and rinse flask and contents with 150 c.c. of cold, recently-boiled distilled water. Add rinsings to main solution in the beaker, bring final volume to about 300 to 350 c.c. and titrate quickly with standard iodine solution and starch to the appearance of a strong blue color.

NOTES: 1. A blank determination should be made on corresponding amounts of reagents treated as above, and the results should be corrected accordingly.

2. If the copper content of the alloy is as high as about 3% or over, it prevents a good end point in the tin titration when the tin percentage is low. Under such conditions, just before titrating, add about 1 gram of KI crystals, stir until nearly dissolved and titrate immediately. If allowed to stand too long at this point, trouble may be encountered from the precipitation of some of the other constituents.

3. Other forms of pure iron may be employed, but the wire as above specified has been found convenient.

CHAPTER XXXI

FOUNDRY DATA

LIKE other workers, the foundryman frequently has a lapse of memory regarding certain figures and calculations, so a few suitable tables and other matter is included under this head. For these we are indebted to the Smithsonian Physical Tables by Fowle, Circular 47 of the U. S. Bureau of Standards, Catalog 48 of the Hendrie & Bolthoff Mfg. & Supply Co., Denver, Fuel by Sexton, Metallurgical Bulletin of the General Engineering Co. of Salt Lake City, First-Aid Manual of the U. S. Bureau of Mines, and other general sources of such information.

Melting points, hardness, specific gravity, and weight of metals

Metal	Melting point, ° C.	Hardness*	Specific gravity	Pounds per cu. ft.	Metal	Melting point, ° C.	Hardness*	Specific gravity	Pounds per cu. ft.
Aluminum....	659	2.0	2.71	163	Nickel.....	1485	.....	8.35	550
Antimony....	630	3.3	6.80	419	Osmium.....	2700	7.0	22.47	
Bismuth.....	271	2.5	9.80	611	Palladium....	1550	4.8	11.9	
Brass (cast)...	1023	3.5	8.10	505	Phosphorus..	44			
Cadmium.....	321	2.0	8.66		Platinum....	1755	4.3	21.40	1344
Chromium....	1515	9.0	6.80		Rhodium....	1950	.....	12.26	
Cobalt.....	1480	.....	8.60		Ruthenium...	1950	.....	12.26	
Copper.....	1096	2.7	8.90	557	Silver.....	960	2.7	10.50	654
Gold.....	1063	2.7	19.32	1208	Steel.....	1375	5.8	7.85	490
Iridium.....	2350	6.0	22.40		Sulphur.....	115	2.0	2.08	125
Iron (cast)....	1530	4.5	7.77	450	Tantalum....	2900	6.0	16.60	
Iron (wrought)	1635	.....	7.75	480	Tin.....	235	1.5	7.28	460
Lead.....	327	1.5	11.36	708	Tungsten....	2985	.....	19.10	
Magnesium....	651	2.0	1.74		Vanadium....	1720	.....	5.50	
Manganese....	1230	5.0	7.39	499	Zinc.....	419	2.5	7.10	437
Mercury.....	-39	.....	13.58	849	Zirconium....	1700	4.5	4.70	
Molybdenum...	2550	.....	8.56						

* In the scale of hardness, the diamond is 10 and talc is 1.

Comparison of thermometers

	Centigrade	Fahrenheit
Boiling point, degrees.....	100	212
Freezing point, degrees.....	0	32

To convert Centigrade to Fahrenheit:

$$\frac{5(F. - 32)}{9} = C.$$

and to convert Fahrenheit to Centigrade:

$$\frac{9C.}{5} + 32 = F.$$

Pyrometry.—The accurate measurement of temperatures in foundries is a more or less neglected operation, yet it is of importance; and as temperatures cannot be measured directly, some instrument is necessary, hence the pyrometer is used for this purpose. Electric pyrometers, indicating or recording, are either of the thermocouple or resistance type for all ranges of temperature up to 1650° C. (3000° F.). If rods of different metals be placed in contact, or soldered together at one end, the other ends being connected with a wire, and the joined ends be heated, a current will be found to flow through the wire, and can be measured. This is the principle of the thermocouple type of pyrometer. In a common type, wires of platinum, and of an alloy of platinum with 10% of rhodium, are used. The junction of these, when heated, starts an electric current, depending on the difference in temperature between the hot and cold ends; and as this current can be measured, it gives a means of determining the temperature of the junction. A galvanometer of the reflecting type is used to measure the current. The junction of the wires is placed in the molten metal, and as it gets hot, the current flows and deflects the galvanometer needle, the position of which is then read. This type of instrument is very accurate, to 1° at temperatures over 1000° C.

Visible heat

Appearance	Approximate temperature, °C.	Appearance	Approximate temperature, °C.
Luminous.....	500	Dull orange.....	1150
Dull red.....	700	Bright orange.....	1200
Bright red.....	800	White heat.....	1300
Cherry red.....	900	Dazzling white heat.	1500

FUELS

The foundry, according to its geographic situation, may use charcoal, coal, coke, distillates, gas, and petroleum, for heating furnaces, disregarding electricity, so the following data may be of service:

Charcoal.—This is an excellent fuel for many purposes, but as it is very friable and crushes easily if the superincumbent charge be too heavy, it will not bear a heavy weight. Its heating power is high—about 13,700 B.t.u. It is better for heating by contact or open fires where it heats by direct radiation. At high temperatures, large quantities of carbon monoxide gas are given off, and this being very poisonous, care must be taken to have a good draft to carry off the fumes, which are odorless and colorless.

Coal.—Anthracite and bituminous coals are not used much in furnaces for various reasons, but when converted into coke, bituminous coal is burned in great quantity.

Coke.—This is an excellent fuel, especially where it heats either by contact or by radiation, and where flame is not necessary. It has a greater calorific value, weight for weight, than coal. To be able to bear the weight of a crucible full of metal, or to bear the weight of a charge in a cupola, coke must be dense and have a high crushing strength.

Distillates.—These include such products as benzol, gasoline, and naphtha, and when used as fuels they are atomized by air and forced into the furnace. The heat is easily regulated, and the labor is light.

Gas.—Either natural or manufactured gas may be employed in furnaces. Like distillates, any required temperature can be maintained with perfect regularity for any period; and the flame can be regulated to be oxidizing, reducing, or neutral, as desired. Perfect combustion can be maintained, and much higher temperatures can be attained than is possible with solid fuel, as both the air and gas can be heated to a high temperature by means of regenerators before combustion.

Petroleum.—This is burned similarly to distillates, but must be heated. Apart from the ease in manipulation, fires are started quickly and may be extinguished at any moment, and a maximum temperature is soon attained.

Specific gravity.—The specific gravity of a substance is equal to its weight divided by the weight of an equal volume of distilled water at 4° C. (39° F.). In other words, the specific gravity of a solid or liquid is the ratio of weight (mass) of the body to the weight (mass) of an equal volume of water under standard conditions. Pure water is taken as 1.00. Ordinary room temperatures (60° F.) are considered as standard for determinations.

For specific gravities less than unity, the values are calculated from the formula:

$$\text{Degrees Baumé} = \frac{140}{\text{specific gravity}} - 130,$$

and for specific gravities greater than unity from:

$$\text{Degrees Baumé} = 145 - \frac{145}{\text{specific gravity}}.$$

Tackle blocks.—It is much easier to lift crucibles from pit furnaces, once the tongs are properly adjusted, and pour the metal contents by means of an overhead runway and blocks. With a rope (hemp) over through a single block overhead, a man can lift his own weight, less the friction. When hoisting continually, a man will pull 80 lb., but friction reduces this to 78 lb. When blocks are used in pairs, each sheave in the lower or movable block multiplies this force by 2, so that one man should hoist with a pair of blocks the following: 140 lb. with two singles, 280 lb. with two doubles, and 420 lb. with two triples.

Weight of various alloys (brasses and bronzes)

Alloy	Pounds per cubic foot
Brass:	
Yellow, 70% Cu+30% Zn, cast.....	527
Red, 90% Cu+10% Zn.....	536
White, 50% Cu+50% Zn.....	511
Bronze:	
90% Cu+10% Sn.....	548
85% Cu+15% Sn.....	555
80% Cu+20% Sn.....	545
75% Cu+25% Sn.....	551
German silver:	
52% Cu+26% Zn+22% Ni.....	527
59% Cu+30% Zn+11% Ni.....	520
63% Cu+30% Zn+ 6% Ni.....	518
Lead and tin:	
87.5%+12.5%.....	661
84 %+16 %.....	644
63.7%+36.3%.....	588
46.7%+53.3%.....	545
30.5%+69.5%.....	514
Bismuth, lead, and tin:	
53%+40%+7%.....	659
Wood's metal:	
50% Bi+25% Pb+12.5% Cd+12.5% Sn.....	605
Cadmium and tin:	
32%+68%.....	480
Gold and copper:	
98%+ 2%.....	1176
90%+10%.....	1071
86%+14%.....	1027
Aluminum and copper:	
10%+90%.....	480
5%+95%.....	522
3%+97%.....	542
Aluminum and zinc:	
91%+9%.....	175
Platinum and iridium:	
90%+10%.....	1348
5%+95%.....	1396
Constantin:	
60% Cu+40% Ni.....	554
Magnalium:	
70% Al+30% Mg.....	125
Manganin:	
84% Cu+12% Mn+4% Ni.....	530

- Plug.** Clay shaped to fill the tap-hole of a furnace.
- Pocket.** A cavity.
- Poling.** Refining copper or tin in a reverberatory furnace by means of long poles of green wood—generally small trees. The oxygen is removed by this action.
- Porous.** Spongy; holey.
- Pot.** A crucible or ladle.
- Puddling.** Purifying wrought iron or steel.
- Rabble.** A stirrer.
- Rammer.** A tool for ramming sand in a mold.
- Red-short.** Brittle when hot.
- Refractory.** Complex; difficult to treat.
- Riser.** A feed head.
- Sampling.** To take a representative part of an ore or metal, so that the subsequent analysis gives an average of a lot. Sampling well done is not an easy matter.
- Sand artist.** A facetious term for a molder.
- Scrap.** Spillings; any waste metal.
- Set.** To become solid.
- Short.** Brittle.
- Short-cast.** A casting with insufficient metal.
- Shot.** Spillings like shot.
- Shrinkage.** Contraction of metals while cooling.
- Skimmings.** Dross lifted off from the top of molten metal.
- Skulls.** The metal or slag that sets in the bottom of ladles after casting.
- Slag.** The by-product of smelting, formed by the fluxes, fuels, gangue, and impurities.
- Solid solution.** The specific state of association of two or more substances entirely homogeneous in the solid. An alloy.
- Solution.** The act or process whereby one metal is absorbed into, or homogeneously mixed with, another; also the resulting solid alloy.
- Sow.** A heavy runner which conducts molten metal to molds for making pig.
- Sprue.** Opening into which the molten metal is poured to fill the mold.
- Sweating.** Liquating.
- Treading.** Ramming with the feet.
- Vent.** An air passage for carrying off gases produced in molds during casting.
- Virgin metal.** A newly produced metal—that is, pure and never worked before.
- Waste.** Loss, or a residue which may be re-worked.
- Wind furnace.** One whose draft is produced by natural means, such as a chimney or stack.

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Weight of miscellaneous substances

Material	Pounds per cubic foot	Cubic feet per ton	Material	Pounds per cubic foot	Cubic feet per ton
Brick.....	130	17	Coke.....	45	44
Charcoal.....	14	143	Earth (moist, loose)..	71	32
Clay.....	110	19	Portland cement....	86	25
Coal (anthracite)....	92	24	Sand (dry).....	104	22
Coal (bituminous)...	78	29	Sand (wet).....	123	18

Shrinkage of cast metals while cooling

Metal	Inch per foot	Metal	Inch per foot
Aluminum.....	$\frac{17}{64}$	Iron (cast).....	$\frac{1}{8}$
Bismuth.....	$\frac{3}{32}$	Lead.....	$\frac{5}{16}$
Brass (thin).....	$\frac{1}{8}$	Tin.....	$\frac{1}{4}$
Brass (thick).....	$\frac{5}{32}$	Zinc.....	$\frac{5}{16}$
Copper.....	$\frac{3}{16}$		

Approximate weight of castings from patterns

A pattern weighing 1 lb. and made of	Will weigh when cast in				
	Aluminum	Brass	Iron	Copper	Lead
Red pine.....	....	14.2	12.5	14.8	25.0
White pine.....	4.8	18.5	16.0	19.0	
Yellow pine.....	....	16.2	14.3	17.0	
Oak.....	....	9.8	8.7	10.2	

Avoirdupois weight

27.34	grains = 1 dram (dr.)
16	drams = 1 ounce (oz.)
16	ounces = 1 pound (lb.)
112	pounds = 1 hundred-weight (long ton) (cwt.)
100	pounds = 1 hundred-weight (short ton) (cwt.)
2240	pounds = 1 long ton
2000	pounds = 1 short ton

Troy weight

24	grains = 1 pennyweight (dwt.)
20	pennyweights = 1 ounce (oz.)
12	ounces = 1 pound (lb.)

To convert Avoirdupois into Troy:

Avoirdupois ounce $\times 0.9114$ = troy ounce.

Troy ounce $\times 1.0971$ = avoirdupois ounce.

1 ounce avoirdupois = 437.5 grains = 0.9114 ounce troy.

1 ounce troy = 480 grains = 1.0971 ounce avoirdupois.

1 pound avoirdupois = 7000 grains = 1.2153 pounds troy.

1 pound troy = 5760 grains = 0.8228 pounds avoirdupois.

The metric system.—The foundryman should be familiar with the metric system of weights and measures. The system has been legalized by Congress for use in the United States. Among the advantages claimed are the decimal relation between the units; the extremely simple relations of the units of length, area, volume, and weight to one another; and the uniform and self-defining names of units. The fundamental unit of the metric system is the meter—the unit of length—and from this the units of capacity (liter) and of weight (gram) were derived. All other units are the decimal subdivisions or multiples of these, as shown below:

Prefixes	Equivalent	Unit
milli = one thousandth	$\frac{1}{1000}$ or 0.001	} Meter for length
centi = one hundredth	$\frac{1}{100}$ or 0.01	
deci = one tenth	$\frac{1}{10}$ or 0.1	
unit = one	1	} Gram for weight or mass
deka = ten	$\frac{10}{1}$ or 10	
hecto = one hundred	$\frac{100}{1}$ or 100	} Liter for capacity
kilo = one thousand	$\frac{1000}{1}$ or 1000	

Metric equivalents

METRIC SYSTEM

Length

1 millimeter	= 0.03937 inch
1 centimeter	= 0.3937 inch
1 meter	= 39.3708 inches
1 kilometer	= 0.6214 mile

Square

1 sq. centimeter	= 0.1549 sq. inch
1 sq. meter	= 10.7631 sq. feet
1 are	= 119.5894 sq. yards
1 hectare	= 2.4711 acres

Cubic

1 cu. meter	= 35.3166 cu. feet
-------------	--------------------

Weight

1 gram	= 15.4323 grains
1 kilogram	= 2.2046 pounds
1 tonne	= 2204.55 pounds

Liquid measure

1 centiliter	= 0.0211 pint
1 liter	= 1.0567 pints
1 hectoliter	= 26.4176 pints

U. S. STANDARD

Length

1 inch	= 2.5309 centimeters
1 foot	= 30.4794 centimeters
1 yard	= 0.9143 meter
1 mile	= 1.6093 kilometers

Square

1 sq. inch	= 2.5309 sq. centimeters
1 sq. foot	= 0.0929 sq. meter
1 sq. yard	= 0.8361 sq. meter
1 acre	= 0.4047 hectare

Cubic

1 cu. foot	= 0.02831 cu. meter
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Weight

1 pound	= 0.4536 kilogram
1 cwt.	= 50.8024 kilograms
1 ton	= 1016.0483 kilograms

Liquid measure

1 pint	= 47.3171 centiliters
1 quart	= 0.9563 liter
1 gallon	= 3.7854 liters

Decimal equivalents of fractions of an inch

$\frac{1}{64} = 0.0156$	$\frac{17}{64} = 0.265$	$\frac{33}{64} = 0.515$	$\frac{49}{64} = 0.765$
$\frac{1}{32} = .0313$	$\frac{9}{32} = .281$	$\frac{17}{32} = .531$	$\frac{25}{32} = .781$
$\frac{3}{64} = .0469$	$\frac{19}{64} = .297$	$\frac{35}{64} = .547$	$\frac{51}{64} = .796$
$\frac{1}{16} = .0625$	$\frac{5}{16} = .312$	$\frac{69}{64} = .562$	$\frac{63}{64} = .812$
$\frac{5}{64} = .0781$	$\frac{21}{64} = .328$	$\frac{117}{64} = .578$	$\frac{53}{64} = .828$
$\frac{3}{32} = .0937$	$\frac{61}{64} = .343$	$\frac{109}{32} = .594$	$\frac{267}{32} = .843$
$\frac{7}{64} = .1094$	$\frac{33}{64} = .359$	$\frac{39}{64} = .609$	$\frac{55}{64} = .859$
$\frac{1}{8} = .125$	$\frac{3}{8} = .375$	$\frac{63}{8} = .625$	$\frac{63}{8} = .875$
$\frac{9}{64} = .140$	$\frac{25}{64} = .390$	$\frac{41}{64} = .640$	$\frac{57}{64} = .890$
$\frac{5}{32} = .156$	$\frac{13}{32} = .406$	$\frac{25}{32} = .656$	$\frac{29}{32} = .906$
$\frac{11}{64} = .172$	$\frac{27}{64} = .422$	$\frac{43}{64} = .672$	$\frac{59}{64} = .922$
$\frac{3}{16} = .187$	$\frac{7}{16} = .437$	$\frac{11}{16} = .687$	$\frac{15}{16} = .937$
$\frac{13}{64} = .203$	$\frac{29}{64} = .453$	$\frac{45}{64} = .703$	$\frac{61}{64} = .953$
$\frac{7}{32} = .219$	$\frac{31}{32} = .469$	$\frac{23}{32} = .719$	$\frac{31}{32} = .969$
$\frac{15}{64} = .234$	$\frac{37}{64} = .484$	$\frac{47}{64} = .734$	$\frac{63}{64} = .984$
$\frac{1}{4} = .25$	$\frac{1}{2} = .50$	$\frac{3}{4} = .75$	$1 = 1.000$

Formulas for Areas

CIRCLE

Radius (R) is the distance from the center to the circumference.

Diameter (D) is the distance from circumference to circumference through the center, and is twice the radius.

Circumference is the distance around.

$$\text{Circumference} = D \times 3.1416.$$

$$\text{Area} = 2R \times 3.1416.$$

$$\text{Area} = D^2 \times 0.7854.$$

Areas of circles are to each other as the squares of their diameters.

$$\text{Side of inscribed square} = D \times 0.7071.$$

$$\text{Side of equal square} = D \times 0.88623.$$

$$\text{Side of circumscribed square} = D.$$

SPHERE

$$\text{Surface area} = D \times \text{circumference}.$$

$$\text{Surface area} = D^2 \times 3.1416 = (D \times D \times 3.1416).$$

$$\text{Surface area} = 4 \times \text{area of great circle}.$$

$$\text{Surface area} = \text{convex surface of circumscribing cylinder}.$$

Surface of spheres are to each other as the squares of their diameters.

$$\text{Volume} = D^3 \times 0.5236 = (D \times D \times D \times 0.5236).$$

$$\text{Volume} = \frac{2}{3} \text{ volume of circumscribing cylinder}.$$

Volumes of spheres are to each other as the cubes of their diameters.

$$\text{Sides of equal cube} = D \times 0.806.$$

Power Units and Relations

One horsepower equals:

550	foot-pounds per second
33,000	foot-pounds per minute
1,980,000	foot-pounds per hour
2445	B.t.u. per hour
746	watts, or 0.746 kilowatt
4562	kilogram-meters per minute
0.986	metric horsepower

One foot-pound is the work required to raise 1 lb. 1 ft., or overcome the resistance of 1 lb. for 1 ft.

One British thermal unit (B.t.u.), equal to 778 foot-pounds, is the heat required to raise 1 lb. of water 1° F. (from 62° to 63°). Average bituminous coal contains 12,000 to 14,000 B.t.u.

Electrical units.—Volt is the unit of electrical pressure, electromotive force, or difference of potential.

Ohm is the unit of electrical resistance.

Ampere is the unit of electrical current, or rate of flow of electricity.

Watt is the unit of electrical power; that delivered by 1 ampere at 1 volt pressure; 746 watts = 1 horsepower, and 1000 watts = 1 kilowatt.

Power factor is the ratio of actual watts to the product of current and voltage from switchboard readings.

Kilowatt-hour = 1.34 horsepower-hour.

Ores and finished metals.—The foundry that wishes to instruct its men on the source of metals, and the steps in handling them to the cast product, can obtain from the United Projector & Film Corporation, of 69 West Mohawk Street, Buffalo, N. Y., a moving picture film entitled, "From Mine to Molder." It consists of four reels of standard size, and is very instructive.

Altitude effects

Elevation above sea-level, feet	Barometer, inches	Pressure, lb. per sq. in.	Boiling point, ° F.
0	30.00	14.72	212
1,000	28.85	14.17	210
2,000	27.82	13.64	208
3,000	26.82	13.13	206
4,000	25.85	12.64	204
5,000	24.92	12.17	202
6,000	24.00	11.71	201
7,000	23.1	11.27	199
8,000	22.17	10.85	197
9,000	21.3	10.45	195
10,000	20.34	10.06	193
11,000	19.8	9.69	191
12,000	19.1	9.33	190
13,000	18.3	8.98	188
14,000	17.6	8.64	186
15,000	17.0	8.32	184

System in the foundry.—The state of a foundry floor reveals, in a great measure, the system of conducting the operations of molding. When we see promiscuous piles of sand, scrap bricks, box parts, gagers, and core tackle spread all over the place we have evidence of the absence of method; and it will generally be found in such a foundry that every man is a law unto himself, and is expected to makeshift for himself, rather than to consider the general advantage of the work or the output.—J. F. Buchanan in "The Moulder's Dictionary."

FIRST AID IN THE FOUNDRY

Bruises, strains, sprains, and burns are probably the most frequent injuries to foundrymen, and may be treated as follows:

Bruises.—When a person falls or strikes some part of the body, or is struck by something, often the skin is not broken, but the force of the blow or fall injures the tissues under the skin, breaking many of the small blood vessels. In deep bruises the outer skin is not damaged, but the skin over the bone is likely to show a black and blue spot. If a larger

blood vessel is injured, much blood gathers under the skin, causing great swelling and discoloration. The symptoms are immediate pain from injury to the nerves, swelling, black and blue mark, and later, pain from pressure of the blood on the nerves, which is increased by movement.

Little treatment is necessary, the aim should be to limit swelling and to decrease pain. Apply an ice-bag or towels wrung out in cold water, and rest the injured part, thus diminishing the pain. Always make sure that there is no other injury, such as a broken bone or a dislocation. For a severe bruise it is best to call a physician.

Strains.—A strain means overstretching of the muscles. The most common strains are those of the back, shoulder, ankle, and wrist. A strain may be caused by a sudden wrench, as in lifting heavy weights. In severe strains small blood vessels may be broken so that blood escapes into the muscles.

The injured man should be made to rest for a time. Rub the parts gently with alcohol and water, or with witch hazel to deaden the pain. If the strain is severe, the patient should consult a physician.

Sprains.—A sprain means an injury to a joint. It results from violent stretching, twisting, or part breaking of ligaments about a joint, and is often mistaken for a fracture of the bones. Twisting of the foot or an unnatural movement of a joint may cause a sprain.

The injured joint should be elevated and placed at absolute rest, as often a sprain is accompanied by a fracture. Apply hot or cold towels over the injury several times. Place a cravat bandage firmly around the joint and send the injured man to the doctor.

Burns or scalds.—Fires, gas explosions, and electric current are sources of burns (dry); and steam, hot water, and such like produce scalds.

Remove all loose clothing, but do not try to remove clothing that adheres to the skin—cut around it. In all cases of burns, the air should be excluded from the burned surfaces as quickly as possible by the application of 0.5 to 1%

picric-acid gauze, moistened if possible by steam or clean water. In applying this gauze, be careful not to bandage together open surfaces, such as fingers or toes, or the ears to the side of the head. If the patient is suffering from shock, treat it. The danger from a burn depends upon its depth and extent, also the age and general condition of the person injured. For all burns of the body, except of the chest, back, head, or face, for which there are special dressings, first apply picric-acid gauze and then cover with a triangular bandage, encircling the limbs as in the ordinary dressing for a wound. Do not pull the bandage tight.

Gas.—There is a possibility of men being overcome by carbon monoxide from furnaces and molds when castings have been poured. This gas is odorless and colorless, and if concentrated enough it will overcome a man quickly and without much warning; but if not concentrated, its action may be slow, yet eventually as deadly. The symptoms are numerous, the most pronounced being yawning, giddiness, ringing in the ears, weariness, and a fluttering of the heart (a late symptom). If a person gets out of such impure air into good air, these effects usually pass off, leaving perhaps a headache; but if no attention is paid to them, and he continues working, he becomes more affected and feels his legs beginning to give way; finally he staggers around and sinks to the ground semi-conscious or unconscious.

The best treatment is removal to fresh air, and artificial respiration by the Schaefer or prone method—that is, the patient is laid on his abdomen, with his head resting on an arm, and the operator straddles his thighs, working on him in the usual manner, about 15 times a minute.

A first-aid kit and one or two trained men should be available in every foundry.

GLOSSARY OF TERMS USED IN FOUNDRIES

A heat. A melt, or one charge.

Admixture. A compound formed by mixing metals together.

Ageing. Certain alloys, such as of aluminum, improve in physical properties the older they are. The term really means maturing.

Alignment. In a straight line.

Alloy. A solid solution of two or more metals.

Alloyed. When two or more metals are homogeneously mixed and poured into a pig or bar.

Alloying. The art of mixing two or more metals.

Amorphous. Without form—that is, crystal form.

Analysis. Determination of the constituents of any substance. Analyses are of two kinds, namely, proximate and ultimate. The former tells of the main constituents, and the latter the complete analysis of the main constituents, or of the whole substance. The terms quantitative and qualitative are used to denote whether an analysis has been made for quantities of constituents or for simply detecting their presence.

Annealing. While working a metal, to prevent cracking or splitting, it is heated for a short period, by which means it becomes soft again. Operations such as rolling make metals hard.

Antacid metal. One that resists corrosive acids.

Aqua-fortis. Commercial or slightly impure nitric acid; aqua-fortis is preferred to the pure nitric acid for dipping and pickling operations.

Ash metal. A low-grade alloy made from skimmings and ash from a brass foundry.

Assay. An analysis of ores either by fusion or by chemicals.

Autogenous soldering. Joining two edges of a metal by fusion, without using another metal or solder. Lead may be soldered by this means.

Bail. An arched handle for lifting a ladle by means of a crane.

Banka tin. Tin from the island of Banka, Dutch East Indies.

Banked. Instead of shutting down a furnace entirely, it is banked with a certain amount of fuel and given a minimum of air, whereby it keeps warm, and may be blown-in again without much bother.

Basin. That part of the head which supplies the runners with metal while casting.

Billet. A short and thick bar of metal, suitable for rolling or forging.

Binder. A clamp for gripping the top and bottom sections of a mold while it is being cast.

Blackwash. An emulsion of clay, lampblack, plumbago, or molasses for facing molds.

Blister copper. High-grade metal from the converter, containing gold and silver and some impurities, yet to be refined.

Blowhole. An air-hole in a casting.

Blown-in and blown-out. To light and get a furnace to full running order is to blow it in; and to run out all of the metal, burn out the fuel, and allow the furnace to cool is to blow it out.

Body core. The main core.

Box. A molding box.

Brazing. Hard soldering.

Breeze. Small or fine carbonaceous fuel, such as coal and charcoal.

Butt-core. One that presses against another, making a close joint.

Cast. To pour metal into a mold.

Caster. One who casts molds.

Casting. Any shape that has been cast in metal.

Centigrade. Boiling point, 100 degrees; freezing point, 0 degrees. To convert into Fahrenheit, multiply by 9, divide by 5, and add 32.

Chaplet. A metal stud for holding a core in position in a mold.

Charge. The quantity of metals or ores and fuels constituting one heat for a furnace.

Chilled iron. That which is hardened on the surface by chilling.

Churning. Feeding.

Cleaning. Dressing castings.

Clearance. That part shaved off the joints or prints of a mold to allow for fitting.

Cold-short. Brittle when cold.

Cold-shut. Closed or shut while too cold to become united.

Composition. A mixture formed by uniting two or more substances.

Constituent. That which is part of a compound.

Cope. The top part of a mold.

Core. That part of a mold which shapes the interior of a hollow casting, generally made by loam rammed and dried.

Cupola. A small blast-furnace used by iron-founders.

Dogs. Holdfasts for keeping parts of a pattern or core-box together.

Dowel. A pin fitting into holes in two abutting pieces, such as the halves of a core-box.

Dressing. Cleaning castings.

Dust-bag. A small sack containing plumbago or fine sand used for dusting a finished mold, and also for dusting parting.

Extruded metal. That which is pressed or squeezed into various shapes.

Facing. Plumbago or other dust applied to the face of a finished mold by means of the dust bag; also a mixture of milled sand, sea coal, or flour which is screened directly on the pattern when ramming a mold.

Fahrenheit. Boiling point, 212 degrees; freezing point, 32 degrees. To convert into Centigrade, subtract 32, multiply by 5, and divide by 9.

Feeder. An iron rod used for pumping metal into a casting while it is solidifying.

Filling. Covering or filling defects in castings.

Fin. The ridge left on a casting at the junction of the parts of the mold.

Formula. A symbolic expression of the composition or constitution of a substance. The ingredients for a mixture to make an alloy.

Founding. The melting and casting of metals and alloys.

Foundry iron. That which is ready for melting for casting purposes.

Freezing. The point at which a metal or a charge in a furnace begins to solidify or set.

Gaggers. Pieces of rod iron or cast iron imbedded in a mold to hold it together.

Gangue. The worthless constituents of any ore.

Ganister. A highly silicious sand used for lining furnaces when mixed with fire-clay.

Gate. Channel or opening through which the molten metal enters the mold cavity.

Gate-pin. A vertical runner pattern to form the connection between the pouring head and a casting.

Grain. Texture of a metal.

Green. Damp or moist, when referring to cores or molding sand.

Hangers. Gaggers.

Hot blast. Air heated before passing into a furnace.

Hot-short. Brittle when hot.

Impurities. Foreign substances in a metal, generally deleterious.

Ladle. Any vessel—generally lined with fireclay or brick—by means of which molten metal is conveyed from a furnace to a mold.

Laminated. Layer-like.

Liquation. Separation of one metal from another; or of a metal from an ore, such as antimony from stibnite.

Litharge. Oxide of lead used in foundries as a drier in making oil sand matches principally.

Loam. A mixture of sand, clay, and other materials for making molds.

Lug. A projection from a molding-box.

Lute. To seal a joint with clay, loam, or cement.

Malleable. Capable of being worked by hammering.

Matte. A product obtained when copper or other metals is reduced from its ores. This may contain up to 50 per cent metal, the remainder being sulphides of the metal. The matte is then blown in a converter to blister copper.

Mixture. Two or more ingredients that do not bear a fixed proportion to one another, and which, however, thoroughly commingled, are conceived as retaining a separate existence. An alloy is not a mixture, but a "solid solution" (which see), but the act of adding two or more metals together in a crucible to form an alloy might be termed "mixing."

Mold. Any space in which metal is cast may be called a mold.

Molder. One skilled in the art of molding.

Molding sand. A mixture of loam, sand, clay, sawdust, horse manure, etc.

Native. Any metal that is found free or more or less pure is native.

Natural draft furnace. A furnace through which the air to support combustion is drawn or sucked by a chimney.

New metal Virgin metal; not made from re-melted metal or scrap.

Nowel. The lower half of a mold, sometimes called the drag.

Nugget. A lump of any metal.

Occluded. Gases absorbed by metals are said to be "occluded"; thus silver is capable of absorbing 0.545 of its volume of oxygen.

Odd-side. Sometimes called a "match," is a half mold used to support patterns while making the first half of the mold.

Oil of vitriol. Commercial or slightly impure sulphuric acid.

Orside. A variety of brass, supposed to resemble gold alloys. Contains from 90% copper to 85½%, with from 10% to 14½% zinc, and sometimes small amounts of tin and iron.

Overpoled copper. Copper "poled" to excess, which embrittles and fills it with gas, spoiling it for rolling operations, but improving it for casting purposes, especially for making aluminum bronze.

Oxidation. Combining with oxygen.

Oxide. A compound of a metal and oxygen.

Pattern. A full-size wooden model of the shape to be cast, and made oversize to allow for shrinkage of the metal. For instance, as iron shrinks $\frac{1}{8}$ inch per foot, the pattern would be this much larger than the ultimate size called for.

Pig. Any rough or molded bar of metal.

Pinholes. Minute air-holes in a casting.

Pitted. Marked with hollows, during casting or by corrosion.

